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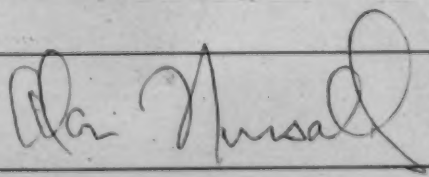

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The Effects of Weather Conditions on the Frequency and Severity of Migraine Headaches in Southwestern Ontario

by

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A THESIS

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Date AUGUST 4, 1981

Abstract

Historical records consistently illustrate the importance that man has attached to the impacts of weather on health. It was not until recently, however, that objective scientific analyses of this relationship were attempted. In this study, one small aspect of this medico-meteorological relationship was examined: the effects of various weather conditions on the incidence of migraine headaches in southwestern Ontario.

Weather is commonly mentioned by migraine sufferers as a factor that seems to trigger the onset of attacks. The particular atmospheric conditions that are most frequently cited are falling barometric pressure, chill winds, glare, thunderstorms, extremes of heat or cold, and specific local winds, such as the European Foehn and the Israeli Sharav.

This study was conducted in the Toronto region of southwestern Ontario using 91 volunteers who kept detailed records of their migraine attacks for a period of nine months (April to December, 1979). The migraine data were then compared with 11 different weather parameters: atmospheric pressure, the rate of change of pressure, temperature, the rate of change of temperature, wind speed, wind direction, precipitation, thunderstorms, air pollution, humidex and a type of synoptic weather classification, weather phases. Day of the week was also examined.

The results indicated that the passage of warm fronts through the Toronto area and the warm tropical air that follows those fronts provoke a significant increase in both the frequency and severity of migraine. Excessive heat and humidity were also associated with a marked increase in migraine frequency. Most parameters, however, yielded no significant results and likely have no noteworthy impact on migraine.

The relationship between migraine and atmospheric pressure was examined further in an informal and subjective inquiry into the frequency of migraine attacks during airplane flights. Changes in pressure only seemed to be of significance when they were of large magnitude and happened quickly.

Possible causal mechanisms in the effects of weather on migraine are discussed. Migraine attacks resulting from weather are probably the result of both physiological and psychological stress imposed by unfavourable weather conditions. The physiological stress may be mediated by serotonin, a hormone central to both migraine and

thermoregulation, but this is unsubstantiated.

The following report also includes an introduction to human biometeorology and an overview of the mechanisms involved in migraine. The concept of weather phases is described in detail.

Acknowledgements

Many people gave their valuable time and advice to bring this project to completion. I owe a substantial debt of gratitude to Mr. David Phillips of the Atmospheric Environment Service in Toronto for providing time, patience and invaluable guidance throughout the duration of this study. I must also express my appreciation for the thoughtful assistance and sage advice that my supervisor, Dr. Keith Hage, has given in the preparation of this thesis. Additional thanks go to Dr. Stanley Greenhill and Dr. E.R. Reinelt for serving on my thesis committee and contributing valuable suggestions.

Generous support was also provided by the Migraine Foundation of Toronto and particularly Rosemary Dudley, Executive Director, who provided the impetus to get this project started. The original computer programs were prepared by Mr. Angus McIntyre. The Atmospheric Environment Service is gratefully acknowledged for providing funding and computer time.

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One last note of thanks is due to the little people in 2-11 (and environs) who made it fun, and Jim for being clued in on Textform. And a special thank-you to Cathy.

Table of Contents

Chapter		Page
I.	Introduction	1
	A. Objectives of the study	2
II.	The Concept of Human Biometeorology	4
	A. Introduction	4
	B. Human Biometeorology	6
	C. The medical impacts of weather on man	10
	Weather and disease:	10
	Weather and mortality:	15
	Major works in medical biometeorology	17
III.	Background to Headache and Migraine	20
	A. The various types of head pain	20
	B. Pain Production in Migraine	26
	C. Migraine and its Variants	27
	Classic migraine:	29
	Common migraine:	29
	Atypical forms of migraine:	30
	D. The Migraine Personality	31
	E. Migraine Triggers	31
	F. The Pathogenesis of Migraine	34
	Serotonin:	35
	Prostaglandins:	36
	Histamine:	37
	Central vasomotor dysregulation:	37
	Conclusions:	38
IV.	A Review of the Literature on Weather and Migraine	39
	A. Historical antecedents	39
	B. Weather-migraine studies	40
	C. Glare and bright light	40
	D. Barometric pressure	41

E. Local winds 42
F. Weather phases 43
V. Weather Phases 46
A. Rationale behind the scheme 46
B. Description of the phases 48
C. Biometeorological research using weather phases 51
D. Weather phases in Toronto, April to December, 1979 53
VI. Methods 67
A. Background 67
B. Data collection 67
C. Data analysis 69
VII. Results 71
A. Weather phases: 71
B. Wind direction: 71
C. Wind speed: 74
D. Atmospheric pressure: 74
E. Temperature: 77
F. Humidex: 77
G. Precipitation: 77
H. Thunderstorms: 77
I. Air pollution: 81
J. Day of the week: 81
VIII. The Impact of Weather on Migraine 82
A. The effects of weather phases 82
B. The effects of wind direction 84
C. The relationship between humidex and migraine 85
D. The effects of atmospheric pressure 86
E. The effects of temperature 87
F. Other meteorological parameters 87
G. Daily and seasonal effects 88
IX. A Brief Investigation into the Effects of Atmospheric Pressure Under Semi-Controlled Conditions 91

X. Conclusions 94

A. Summary of the results 94

B. Implications for further research 95

REFERENCES 97

List of Tables

Table		Page
II.1	Relationship between weather receptors and meteorological stimuli	9
III.1	Symptoms accompanying migraine attacks in 500 patients	25
III.2	Some common precipitating factors in migraine	32
V.1	The meteorological characteristics of weather phases	50
VI.1	Demographic breakdown of sample	68
IX.1	Susceptibility to migraine during flight	93

List of Figures

Figure		Page
II.1	A model of the mechanisms of medical biometeorology	8
II.2	A simple model of comfort based on climate	11
II.3	Faulty thermoregulation in asthmatics	14
II.4	Increase in mortality during the heat wave of 1966, New York City	16
II.5	Mortality in the over-65 age group during the English heat wave of 1966	16
III.1	Typical activity of the cranial arteries during a migraine attack	22
III.2	The main arteries of the head	23
III.3	The age of onset of migraine	24
III.4	The average duration of migraine attacks	24
III.5	The frequency of migraine attacks	24
III.6	The main nerves in the head	28
IV.1	The effects of weather phases on migraine, (Brezowsky, 1964)	44
IV.2	The effects of weather phases on migraine, (Kugler, 1972)	45
IV.3	The effects of weather phases on migraine, (Kugler and Laub, 1978)	45
V.1	Succession of weather phases through an idealized cross-section	49
V.2	The effects of weather phases on nine different clinical complaints	52
V.3	The relative frequency of occurrence of each phase	54
V.4	Temperature-humidity environment for each phase, April to December, 1979, Toronto	55
V.5	The temperature-humidity environment for each phase during July	57
V.6	The temperature-humidity environment for each phase during December	58
V.7	The variation in temperature and dew point for each weather phase during summer	59
V.8	Progression of weather phases in Southwestern Ontario, August 31 to September 4, 1979	61
VII.1	The effect of weather phases on migraine frequency	72
VII.2	The effect of weather phases on the severity of migraine attacks	72

Figure Page

VII.3 The effect of wind direction of migraine frequency 73

VII.4 The effect of wind direction on the severity of migraine attacks 73

VII.5 The effect of wind speed on migraine frequency 75

VII.6 The effect of atmospheric pressure on migraine frequency 75

VII.7 The effect of changing pressure on migraine frequency 76

VII.8 The effect of changing pressure on the severity of migraine attacks 76

VII.9 The effect of temperature on migraine frequency 78

VII.10 The effect of temperature change on migraine frequency 78

VII.11 The effect of humidex on migraine frequency 79

VII.12 The effect of precipitation events on migraine frequency 79

VII.13 The effect of thunderstorms on migraine frequency 80

VII.14 The effect of air pollution on migraine frequency 80

VII.15 The effect of day of the week on migraine frequency 80

VIII.1 Monthly variations in migraine frequency 89

I. Introduction

This project was conceived to investigate certain aspects of the influence that the atmosphere and its changing weather patterns have on human health. It should come as no surprise that weather exerts some control over the well-being of the human body, for it is the atmosphere which impinges directly on the body and with which the body is constantly interacting. This interaction occurs not only across the immediate exterior of the body, but also, and perhaps more importantly, within the lungs and the respiratory tract. It is certainly a situation analogous to the fish in the sea; just as the fish are sensitive to changes in their aqueous environment, so are we sensitive to changes in our atmosphere.

Naturally, health is a function of many factors. It is basically governed by the body's capacity to cope with both internal and external deleterious stimuli. In order to maintain homeostasis, the body reacts continuously to offset the effects of any stimulus that may disrupt that stability. If a stimulus is severe enough, or if the body's protective mechanisms over-react, pathological conditions may develop.

Because the atmosphere maintains such an intimate interaction with the body, it is a significant external stimulus. Physiological response to atmospheric conditions is a perpetual process, as the body is sensitive to atmospheric parameters, such as temperature, light and humidity, among others. As with other stimuli, if the body is incapable of offsetting the effects of various atmospheric conditions, certain clinical ailments may develop.

The ultimate goal of any study in human biometeorology is to determine to what extent the atmosphere and its changes, which we call weather, affect day to day physical and mental well-being. It has been consistently demonstrated that meteorological factors do, to varying extents, affect different ailments. The significance of these factors can change markedly, depending on the individual, the ailment and geographical location. It can be shown, however, that certain diseases cause the sufferer to become increasingly sensitive to specific weather parameters. Migraine appears to be one of these.

The prospect that weather may exert some control over migraine was first brought to the attention of the Atmospheric Environment Service by Rosemary Dudley of the Migraine Foundation of Toronto. The Foundation was concerned with the lack of

interest in the topic, especially in view of the widely held belief among those suffering from migraine that weather was a significant factor in their attacks. The Foundation exhibited particular interest in the physiological effects that falling atmospheric pressure may have. Much of the feedback that the Foundation had received from their members indicated that falling pressure was commonly thought of to be a migraine trigger. Another frequently mentioned trigger was thunderstorms.

Thus, under the auspices of the Atmospheric Environment Service, the project began to gather information, both medical and meteorological, in January, 1979. Unfortunately, due to printing and mailing delays, most volunteers did not begin recording until April. The data collected during the first three months of the year proved insufficient to provide meaningful results and was therefore abandoned. Data collection continued until December, 1979.

A. Objectives of the study

The major purpose of this research is to assess the impact that different meteorological conditions have on attacks of migraine headache. In order to best achieve this goal, five minor objectives can be identified, as listed below. Each is a vital component in the complete understanding of the migraine–weather connection.

1. Is it possible to identify certain types of weather or weather parameters that seem to provoke a measurable increase in the incidence of migraine? That is, can weather be shown to be a migraine trigger? The word "trigger" in this sense is used to denote a factor that tends to induce an attack of migraine in those susceptible. A migraine trigger, of which there are many, is not an agent in the root cause of migraine, but rather will predispose those who suffer from migraine to an attack.

2. Does weather in any way affect the severity of attacks? It has been suggested that weather may not be significant in actually triggering migraine, but rather it tends to increase the severity of attacks already in progress.

3. If weather does indeed seem to affect migraine frequency and/or severity, just how

significant a factor is it? Does it trigger a large proportion of attacks or does it only tend to affect a few sensitive members of the migraine population?

4. Are the results compatible with previously published findings regarding both weather and migraine in particular and weather and health in general?

5. What are the patho-physiological mechanisms that cause weather to influence migraine? It is not likely that this study will generate any satisfactory answer to this question, particularly in view of the largely mysterious causes of migraine, but certain relationships should make themselves clear and may help to increase the understanding of both migraine and its connection to atmospheric conditions.

II. The Concept of Human Biometeorology

Whoever would study medicine aright must learn of the following subjects. First he must consider the effects of each of the seasons of the year and the differences between them. Secondly, he must study the warm and cold winds, both those which are common to every country and those peculiar to a particular locality. With the passage of time and the change of the seasons, he would know what epidemics to expect, both in the summer and the winter, and what particular disadvantages threatened an individual who changed his mode of life. Being familiar with the progress of the seasons and the dates of rising and setting of the stars, he could foretell the progress of the year. Thus he would know what changes to expect in the weather and, not only would he enjoy good health himself for the most part, but he will be very successful in the practice of medicine. If it should be thought that this is more the business of the meteorologist, then learn that astronomy plays a very important part in medicine since the changes of the seasons produce changes in the mechanism of the body.

Hippocrates
Airs, Waters, Places
circa 400 B.C.

A. Introduction

The recognition that weather can significantly affect organic processes is not new, as evidenced by the writings of Hippocrates some 2400 years ago. Today, there are few people who will deny that weather in some way affects their constitution. In a survey of physicians across the U.S., Licht (1964) found that 92% had a firm belief in a weather–health relationship. This association is even given subtle acknowledgement in everyone's vocabulary. Certainly the most common example is the notion of referring to minor respiratory ailments as "colds", a clear reference to the season in which they prevail. Another instance can be seen in the phrase, "under the weather", used to indicate ill–health.

Although weather has long been accepted as influencing life processes, it was not until recently that any methodically sound analyses had been attempted. Pioneering works by Petersen (1938, 1947), De Rudder (1952) and Tromp (1963) heralded the advent of the science of biometeorology by incorporating experimentation, observation and statistical analysis into their methods and producing results that could be scientifically substantiated.

In 1970, the International Society of Biometeorology (I.S.B.) defined biometeorology as follows: "Biometeorology [1] is the study of the direct and indirect effects (of an irregular, fluctuating or rhythmic nature) of the physical, chemical and physicochemical micro- and macro-environments, of both the earth's atmosphere and of similar extra-terrestrial environments, on physicochemical systems in general and on living organisms (plants, animals and man) in particular." In simpler terms, this means that the purpose of biometeorology is to assess the effects that the atmospheric environment has on the processes of life. The main objective of biometeorology is to focus on the dynamic and continuous interface between organism and environment (Tromp, 1964). The atmosphere is not a system of discrete weather parcels, but rather a continuous progression of ever-changing conditions. Thus, organic response must also be continuous. The result is a perpetual sequence of physiological responses and adaptations on the part of the organism to its atmospheric environment, the magnitude of the response depending on the magnitude of the stimulus. This applies to all living organisms, both plant and animal.

Biometeorology, as the name implies, is an interdisciplinary science. It borrows from meteorology, climatology, physiology, biology and medicine, but since its main focus is ultimately the relationships between organisms and their environment, it is essentially a component of ecological science (Sargent and Tromp, 1964). Since it is such a diverse field, for convenience it is divided into six major categories: phytological (plants), zoological, human, cosmic (the effects of extra-terrestrial factors), space (the effects of both the micro-climate of spacecraft and extra-terrestrial environments) and palaeo-biometeorology (the influence of past climates on evolutionary biology). We will concern ourselves solely with human biometeorology.

---

[1]The term *bioclimatology* can be considered to be synonomous with *biometeorology*, by definition of both the I.S.B. and the W.M.O. *Biometeorology* is the accepted term since meteorology essentially encompasses the field of climatology.

B. Human Biometeorology

Human biometeorology can be defined as the study of the impact of weather and climate on both healthy and diseased man. Although the physicochemical structure of the human body is relatively stable, it does make measurable changes and adaptations in response to the surrounding meteorological environment. As Petersen (1940) said, "Weather change requires bodily change. The greater the change in air, the more sudden the change, the greater the organic change; the more frequent the change, the greater the physiological adjustment that is required" (p. 170). The cardinal objective of human biometeorology is to determine the significance of these responses in their effects on human efficiency. In most cases, weather plays only a small role in health, but under certain conditions it can be shown that atmospheric conditions do provoke noteworthy physiological, pathological and psychological responses.

Man's most overt reactions to weather are physiological, that is, certain physical and chemical functions within the body can be triggered by meteorological stimuli. Probably the best examples of this are the responses to temperature. Since man is a homeotherm, a complex system of physiological mechanisms is present to help maintain a constant body temperature. Under cold stress, increases in basal metabolism, shivering, peripheral vasoconstriction, and instinctive postural changes that reduce the surface-to-volume ratio of the body all help to conserve heat. Under an excessive heat load, perspiration, decreased metabolism and peripheral vasodilation act to dissipate body heat.

These reactions are mediated through five principal centers which are receptive to weather conditions. The five are as follows: i) the skin, which contains thermoreceptors and is directly affected by solar radiation, particularly in the production of vitamin D and in changes in pigmentation; ii) the lungs and throat (respiratory tract), which are affected by temperature, humidity and pollution, among others; iii) the mucous membranes of the nose, which are sensitive to airborne contaminants; iv) the eyes, which assist in governing hormonal outputs of the pituitary and the hypothalamus (Benoit-Miline Effect; Hollwich, 1974) and also diurnal biological rhythms controlled by the pineal gland (Wurtman, *et al*, 1968), through direct neural stimulation by sunlight; and v) the central nervous system, which may be affected by electromagnetic phenomena (Reiter, 1974)

and possibly cosmic rays. For a more detailed description of the relationship between stimulus and receptor, see Tromp (1980, pp. 55–59).

Another possible result of meteorological stress is acclimatization. When a person is subjected to a pronounced change of climate, such as moving from a cold climatic zone to a hot one, or even during seasonal changes in the higher latitudes, a period of physiological adaptation takes place that acts to reduce the stress imposed by the weather change and allows the individual to function more efficiently in the new environment. The length of time it takes to acclimatize and the degree of acclimatization depend on one's physiological and emotional adaptability.

In addition to reacting physiologically, man may also exhibit a psychological response. Although the investigation of weather's impact on the mental state and behavior of individuals is fraught with subjectivity, there are few who would deny that weather can significantly alter moods. If weather can impose a psychological stress, then it seems reasonable to assume that the stress can be manifested physiologically by hormonal responses, such as catecholamine (adrenaline) secretion. For this reason, it can be argued that man's emotions, or moods, are also important in registering meteorological stimuli. Historical records show that man has consistently ascribed certain behavioral and cultural traits to ambient weather conditions (Kevan, 1976). The effects, however, will vary greatly between individuals, depending on the circumstances. For instance, rain may upset the baseball fan, but enthuse the farmer.

Table 2.1 lists the the body's main weather receptors and to which of the major meteorological stimuli they are sensitive.

If a meteorological stress is severe enough or lasts long enough, it may ultimately cause or worsen certain pathological conditions in some people. Sulman (1976) estimates that about 30% of a normal population are clinically sensitive to the effects of weather. This "weather-sensitive" group will exhibit recurrent disorders such as attacks of asthma or arthritic pain during particular types of weather. Women appear to be far more sensitive to changes in weather, as are the elderly.

Figure 2.1 presents a model of the processes involved in human biometeorology. Although everyone responds physiologically to particular atmospheric conditions, a significant proportion also find that certain weather situations tend to provoke an

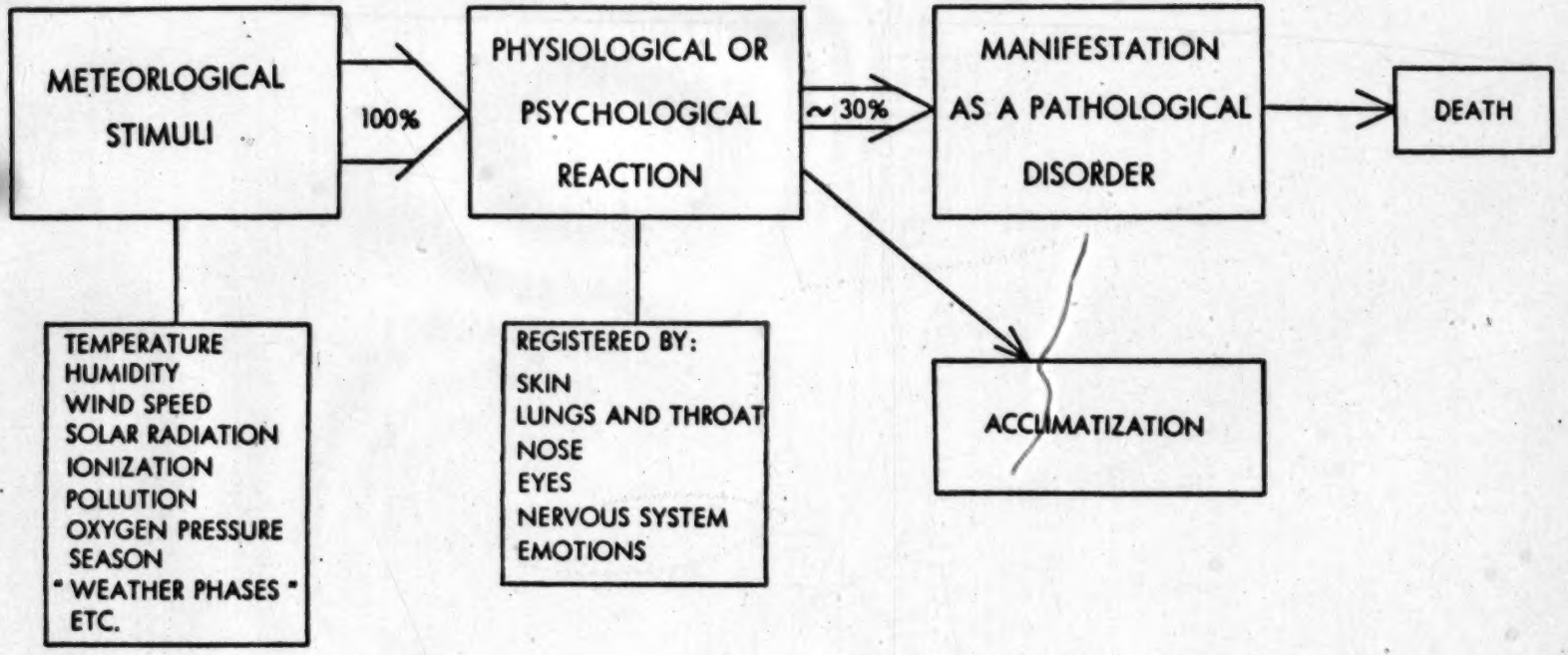


Fig. 2.1: A model illustrating the basic mechanisms underlying the medical impact of weather conditions. Virtually everyone exhibits certain physiological responses to meteorlogical stimuli, such as vasodilation of peripheral blood vessels during heat stress. However, the number of people that will ultimately respond with subjective clinical complaints, ie., those who are " weather-sensitive ", is considerably smaller, closer to 30%. (Data collected from Sulman, 1976; Tromp, 1980)

Table 2.1: The relationship between the prinicipal centers of the human body registering meteorological stimuli and those weather parameters having a significant impact on health. "Emotions" refers to the psychological state or mood of an individual. Data based largely on Tromp (1980).

RECEPTORS: / WEATHER PARAMETERS	Skin	Lungs & throat	Nose	Eyes	Nervous system	Emotions
Temperature	X	X	X	X		X
Humidity	X	X	X			X
Wind speed	X			X		X
Solar radiation	X			X		X
Ionization		X				
Pollution & aerosols	X	X		X		X
Oxygen pressure		X				
Ozone		X				
Glare and flickering				X		
Cosmic rays					X(?)	
Darkness	X			X		X
Electro magnetic long waves (sferics)					X(?)	
Season						X

increase in the frequency and/or severity of particular clinical disorders. Under severe and persistent conditions, death may occur, most readily evidenced by the effects of heat waves (Landsberg, 1969; Tout, 1978). Most people, however, are capable of responding to a persistent meteorological stress by undergoing a degree of acclimatization.

Of all the meteorological parameters, four can be considered to be the most significant in their impact on man. These are temperature, solar radiation, humidity and wind speed (Landsberg, 1972). The most overt patho-physiological responses of the human body result from temperature effects. Thermoregulation is largely controlled by the anterior hypothalamus (Myers and Waller, 1978) which in turn exerts control over the pituitary gland and many of its wide-ranging hormonal functions. This helps explain why thermal stress can have such a profound influence on so many different functions (Tromp, 1980). Solar radiation has wide-ranging effects on the body. In addition to controlling the thermal regime of the atmosphere, direct solar radiation affects the skin, hormonal regulation and vitamin production. Humidity and wind speed both have profound effects on the temperature of the air as perceived by the human body.

Figure 2.2 is a simplified representation of the interrelationships between the four main weather parameters and physical comfort. The diagram was formulated by Olgyay (1963) and is designed for application in the central United States for a lightly-clothed person doing no more than light work. In the winter, the comfort zone is slightly lower, since seasonal acclimatization takes place.

A growing school of thought argues that atmospheric ionization also has a profound effect on health (Krueger, 1972; Sulman, 1976). Positive ions apparently have a deleterious effect, while negative ions seem beneficial.

C. The medical impacts of weather on man

Weather and disease:

Pathologic disorders result from a variety of etiological factors. It is often difficult to assess the relative importance of any one. In some cases, one of these factors is weather. Weather and climate can influence disease through their effects on the regulatory systems of individuals and on the survivability of infectious agents.

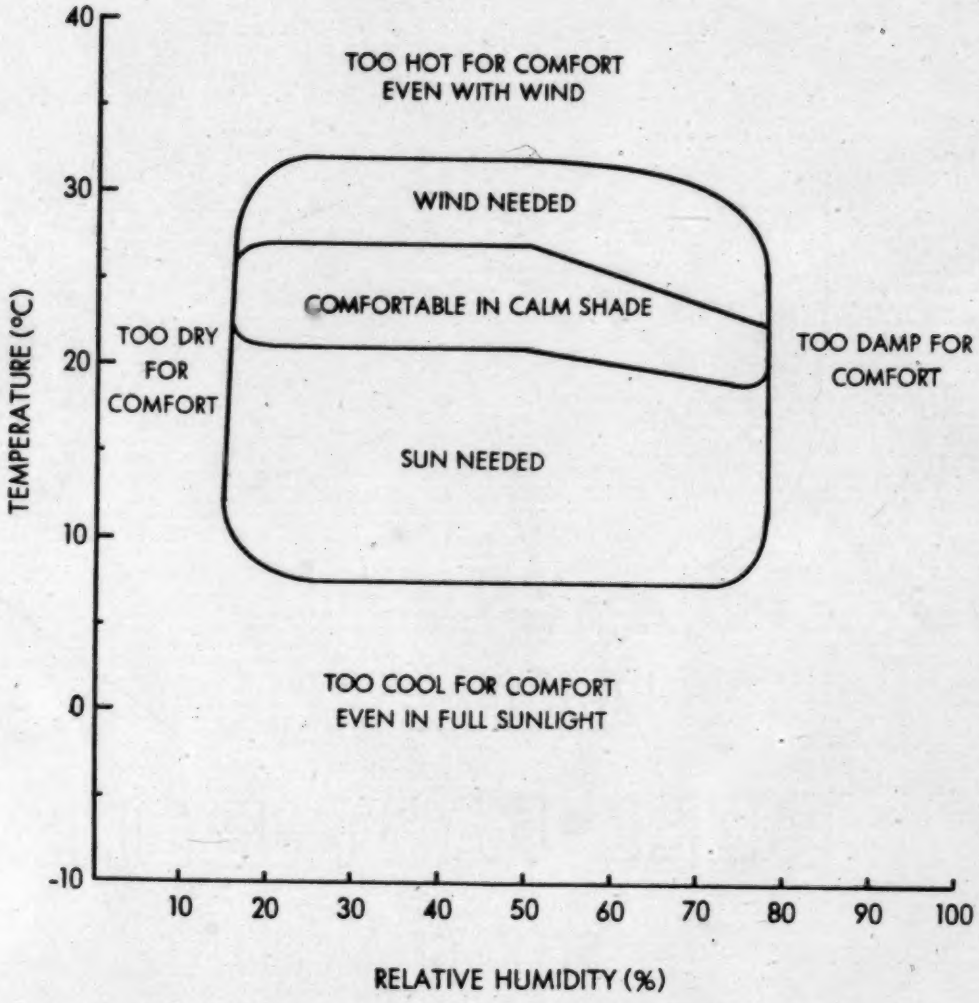


Fig. 2.2: Simple diagram of human comfort as it relates to temperature and humidity. The outlined areas indicate varying degrees of comfort. (Olgyay, 1963; modified in Landsberg, 1972)

An example of the latter effect can be seen in the case of yellow fever. Infectious diseases are quite obviously generated by bacteria or viruses, but their spread is largely dependent upon factors that control the spread of the causative agent. In yellow fever, the mosquito that carries the virus is only able to survive in specific tropical and subtropical regions, largely for climatic reasons (Brown, 1977). This is an example of how climate can limit the geographical extent of a disease.

In some pathologic disorders, weather and climate can be cited as one of the primary factors. Obvious examples include heatstroke and hypothermia, although they also depend on the physiological responses and adaptability of the individual. One serious disease that has a profound meteorological connection is skin cancer (Mackie, 1977). Excessive exposure to high intensity solar radiation increases the risk of acquiring the disease. One of the major concerns arising from stratospheric ozone depletion by man-made pollutants is the likely increase in the prevalence of skin cancer since a reduction in ozone concentration would allow greater amounts of ultraviolet radiation to reach the earth's surface (Kellogg and Mead, 1976). Interestingly, skin cancer is virtually non-existent in the dark-skinned peoples of the world, whose pigmentation affords effective protection against solar radiation. This is an excellent example of what is probably a climatically-induced adaptation in man for tropical survival (Brace, 1970). On the other hand, the highest incidence of skin cancer in the world is in tropical Queensland, Australia, populated almost entirely by fair-skinned people.

The role of weather in disease causation is usually harder to define, however. Almost everyone is familiar with the supposed flare-ups of arthritic pain that sufferers claim during certain weather conditions. Their complaints appear to be valid (Lawrence, 1977), although exactly why is difficult to tell. This is often the case. There are many examples of clinical ailments that have been statistically correlated with particular weather situations, but the complications arise in determining just how the atmospheric conditions may be stimulating the pathological response, and to what extent the atmospheric conditions are significant. Solving these two problems has obvious implications for both therapy and the greater understanding of physiological mechanisms.

Arthritic diseases appear to be often associated with certain weather conditions. Rose (1974) found a good correlation between exacerbations of arthritic pain and both

high relative humidity and rainfall. Tromp and Bouma (1970) discovered that 100% of their sample of arthritic patients had inefficient thermoregulation and thus were likely sensitive to temperature changes.

Faulty thermoregulation was also found in asthmatics (Figure 2.3). After a pronounced cooling of the left hand in an ice water bath, all asthmatics tested demonstrated a marked inefficiency in returning the temperature of the cooled hand to its initial level, whereas healthy subjects showed a rapid response. This rewarming inefficiency is present at all times, not just during attacks. Tromp and Bouma (1965) found a marked increase in asthmatic attacks among 75 Dutch children during cool periods. Asthmatics seem to react strongly to rapid changes in temperature in either direction. There may be a link between hypothalamic thermoregulatory function and asthmatic attacks.

Even psychotic diseases, such as schizophrenia, exhibit meteorological relationships. Schizophrenics demonstrate greater unrest during the influx of warm air masses (Tromp and Faust, 1977). Rohden (1933) found an increase in suicide attempts during periods when the hot, dry Foehn wind prevails in Bavaria.

The Foehn and other similar alpine winds have long been believed to have biological effects, both physical and mental. Studies of the Sharav in Israel (Sulman, 1971, 1976) have shown this hot, dry desert wind to elicit three distinct reaction syndromes from various portions of the population. Sulman has termed these three reactions the *Serotonin Irritation Syndrome*, the *Exhaustion Syndrome* and the *Thyroid Syndrome*. Each is characterized by measurable biochemical changes in those susceptible, usually occurring 1 to 2 days before the Sharav. "Foehn disease" in Europe also seems to develop a day or two prior to the arrival of the Foehn. It is characterized by a wide variety of symptoms, including migraine (Brezowsky, 1964). In North America, the Santa Ana in California has been blamed for murder, suicide and violence of all sorts (Anderson, 1975). The Canadian Chinook, on the other hand, seems to be associated with favourable effects by most authors and irritating effects by a few. Anderson (1975) says that the the Chinook is usually a welcome occurrence and Brezowsky (1964) feels that the Chinook makes "an extremely cold winter milder and the transition to spring less violent. It is possible that a sojourn in this climate is associated with favourable biologic

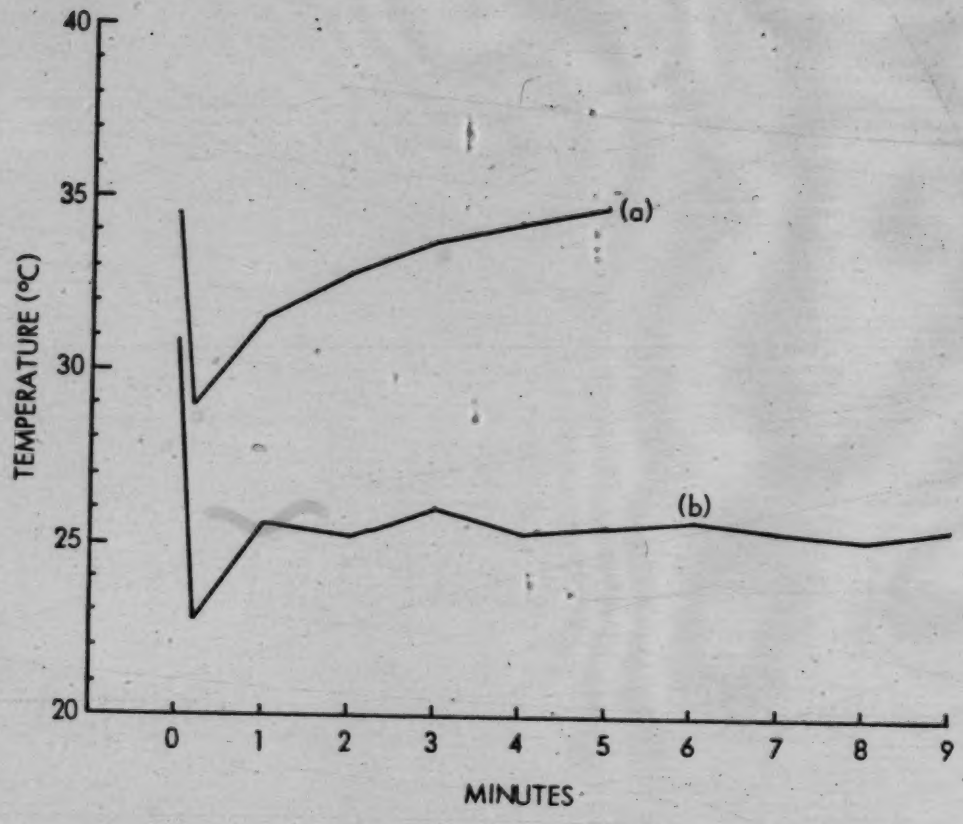


Fig. 2.3: Thermoregulation curves for: (a) a normal healthy subject; and (b) an asthmatic patient. Note the poor response to thermal stress in (b). (After Tromp, 1980)

effects" (p. 396). Unfortunately, there is no concrete evidence either way.

Much more detailed analyses of the relationships between weather, climate and disease can be found in Tromp (1977, 1980). Diseases which appear to exhibit fluctuations in incidence and in severity related to weather are numerous. In most cases, what is unknown are the patho-physiological mechanisms that mediate meteorological stimuli and result in particular illnesses. This has both clinical and economic implications. Understanding the role of the atmosphere in changes in health and disease and utilizing this knowledge in the practice of disease prevention and therapy can only produce beneficial results.

Weather and mortality:

The most dramatic examples of mortality caused by weather are the result of hurricanes, tornados, lightning and floods striking populated areas. But weather can be a more insidious threat. Seemingly innocuous weather conditions can, under the right circumstances, directly or indirectly cause significant loss of life.

In 1952, a large anticyclonic cell of subsiding air trapped pollutants near the surface in London, England, and contributed to the deaths of over 4000 people (Burton, *et al*, 1978). In 1948, a persistent thermal inversion over Donora, Pennsylvania, trapped sulfur and hydrocarbon pollutants in the heavily industrialized valley of the Monongahela River and was responsible for the deaths of 20 people (McDermott, 1961).

Heat waves, particularly in the temperate latitudes, are consistently accompanied by increased mortality. If the physiological regulatory mechanisms designed to reduce heat stress are insufficient or inefficient, then pathological conditions may develop. These include fainting, heat exhaustion, dehydration and heat stroke (Gold, 1964). Death may occur in the elderly and the very young whose circulatory systems are unable to respond.

Landsberg (1969) correlated the mean weekly death rate with the mean weekly temperature in New York City during the heat wave of 1966 (Figure 2.4), showing the effects of heat stress on mortality. Studies of the British heat wave during the summer of 1976 demonstrate a similar association (Tout, 1978). Figure 2.5 illustrates the impact of the heat wave on the elderly in particular. During this period, virtually all excess

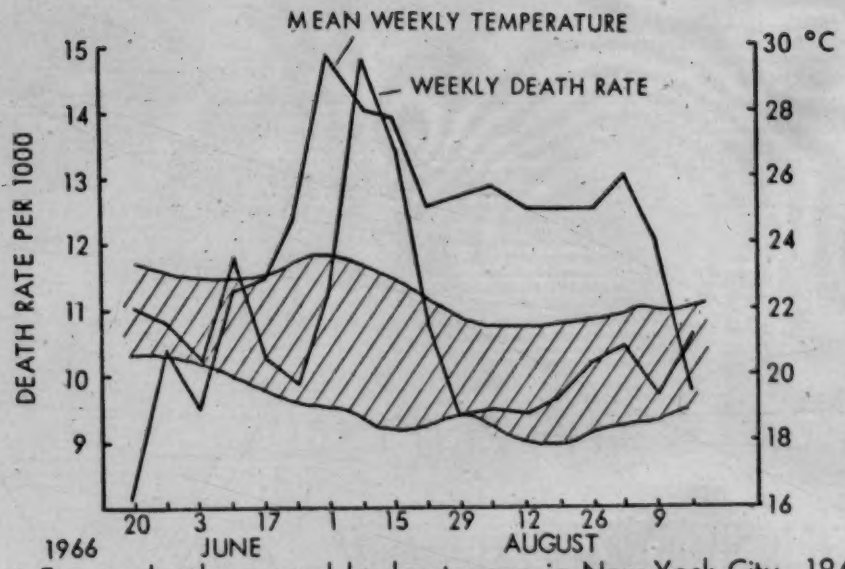


Fig. 2.4: Excess deaths caused by heat wave in New York City, 1966. The hatched zone indicates the expected number of deaths within 95% confidence intervals. (After Landsberg, 1969)

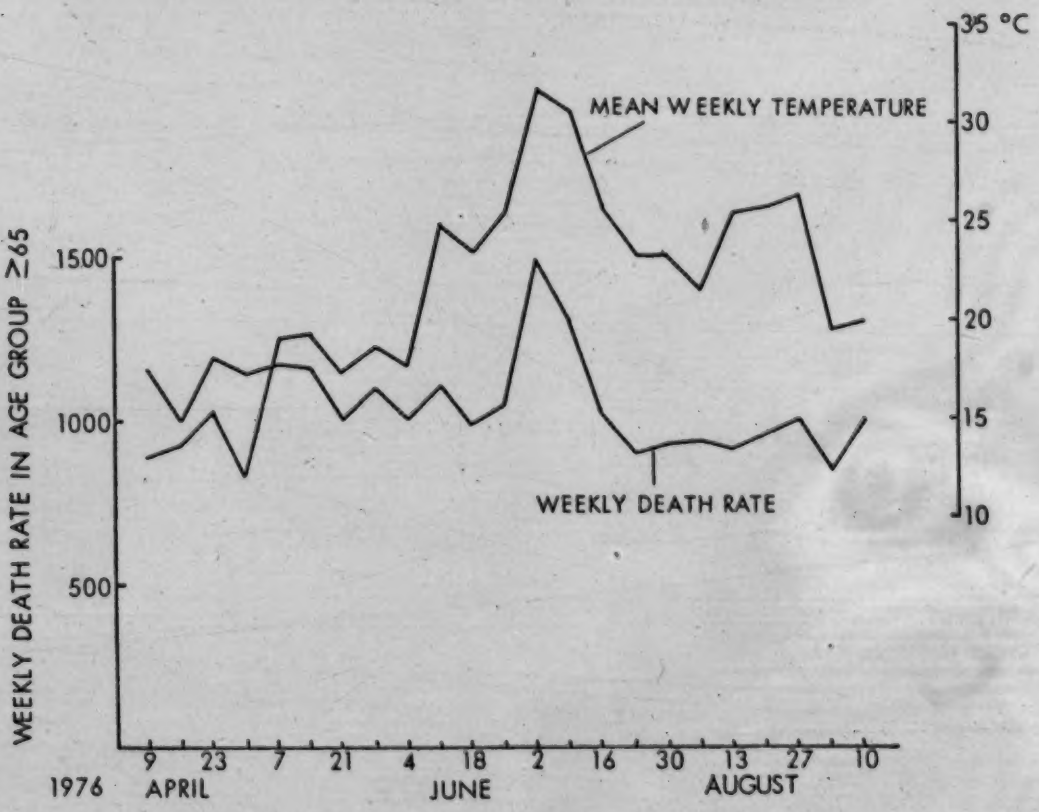


Fig. 2.5: Weekly death rate in Greater London for age group ≥65 during the summer heatwave of 1976. (After Tout, 1978)

deaths occurred in the over-65 age group. There was no coincident rise in mortality among those 4 or under (Macfarlane and Waller, 1976). An interesting point was made by Lyster (1976) who noticed that the rate of mortality rapidly decreases after the initial peak, even though the temperature remains high. This is likely due to the fact that those individuals susceptible to heat stress succumb quickly and there is no longer a significant impact on the remainder.

Marked seasonality in the death rate has been well-documented. Momiyama and Katayama (1966) found a pronounced peak during the winter months in both Japan and Great Britain. Seasonal fluctuations in the U.S.A., on the other hand, were almost non-existent, probably due to more effective artificial control of the indoor environment. This tends to reduce the impact of the outside climate. In Canada, there is also a peak in mortality during winter (Kevan and Chapman, 1980). When broken down by cause, deaths due to respiratory ailments were 78% higher in January than in late summer. Most other causes exhibited similar, although less marked variations, with the exception of cancer which showed virtually no seasonal change whatsoever. Deaths resulting from accidents, poisoning and violence were most frequent in the summer.

Major works in medical biometeorology

The writings of the Greek physician Hippocrates, some 2400 years ago, are a reflection of the keen awareness that many ancient civilizations had of their natural environment. The finest example of this is his dissertation entitled *Airs, Waters, Places*, in which he explains the apparent relationships between health, weather, water and geographical location. In addition, his medical *Aphorisms* contain many references to the impact of atmosphere on health. For example, he reveals the following:

> The changes of the seasons are especially liable to beget diseases, as are great changes from heat to cold or cold to heat in any season. Other changes of the weather have similarly severe effects.
>
> South winds cause deafness, misty vision, headache, sluggishness and a relaxed condition of the body. The north wind brings coughs, sore throats, constipation, retention of urine accompanied by rigors, pains in the side and breast.
>
> As regards the weather in general: drought is more healthy than rain and less likely to provoke fatal illness.

Subsequent research has proven Hippocrates to be remarkably astute.

Sir William Hingston, M.D., (1884) applied Hippocratic medical climatology to the young Dominion of Canada. He assessed the effects that the various climatic types would have on the health of the inhabitants. He concluded that, "The maritime and continental features, harmoniously blended in our climate are, methinks, favorable to the highest development of a hardy, long-lived, intelligent people" (p. 94). In a similar work, Dr. A.N. Bell (1885) described the climate of the continental United States and its clinical effects.

The above quote by Sir William reflects a popular school of thought in the nineteenth and early twentieth centuries. Climatic, or environmental, determinism, as it was called, declared that the forces of the natural environment were the most powerful shapers of the vitality and cultural traits of the world's numerous ethnic groups. Two of the foremost proponents of this school were Drs. Ellsworth Huntington and Clarence Mills, who wrote *Mainsprings of Civilization* (1945) and *Climate Makes the Man* (1942), respectively. Both authors ascribe the technological advancements of man in the temperate zones to climatic factors. As Mills states in the conclusion to his book, "The energetic man of stimulating regions should appreciate the good fortune which placed him under such favorable circumstances. He has no cause for egotism; instead he should give credit to the natural forces which made possible his accomplishments, remembering that *climate makes the man*" (p. 319, author's emphasis). This doctrine has since fallen into disrepute, however, as it ignores the major contributions of political, psychological, nutritive and numerous other factors to cultural destiny. Nevertheless, it does stand as a testament to the importance that is attached to weather in its influence over our lives.

The era of modern scientific medical biometeorology was initiated by Dr. William Petersen with the publication of his monumental four volume work, *The Patient and the Weather* (1938). Although mostly documenting empirical research, it was the first serious attempt to determine the patho-physiological link between clinical ailments and ambient weather conditions.

The next major works on the subject were *Medical Biometeorology* (1963), by S.W. Tromp, and *Medical Climatology* (1964), edited by Sidney Licht. Both works, but particularly Tromp's, provided an exhaustive review of the field. They remained the most

significant references until the publication of *Biometeorology* (1980), also by Tromp.

Other notable contributions include *Weather and Health* (1969) by Landsberg, *Weather and Life* (1972) by Lowry, *Climate and Life* (1974) by Budyko and *Health, Weather and Climate* (1976) by Sulman. A fascinating account of the extent to which climate can be seen as a cultural determinant is given by Robbins (1966) in *Explorations in Psychocultural Bioclimatology* .

A number of monographs and technical memoranda have been written providing concise analyses of fundamental aspects of medical biometeorology. These include *Recent Studies in Bioclimatology* (1954), edited by Sargent and Stone, *A Survey of Human Biometeorology* (1964) by Sargent and Tromp, *The Assessment of Human Bioclimate* (1972) by Landsberg and *The Atmospheric Environment: A study of comfort and performance* (1972) by Auliciems. Detailed syntheses of biometeorological research and extensive bibliographies are contained in the occasional publication, *Progress in Biometeorology*, edited by Tromp and Bouma.

III. Background to Headache and Migraine

A. The various types of head pain

Headache is one of the most prevalent ailments afflicting man, and it is likely that there is virtually no one who, at one time or another, has not been beset with the discomfort it produces. Not surprisingly, the types of head pain are varied as are the causes and symptoms. Head pain can be divided into two major groups, intracranial and extracranial; it is the latter with which most people are familiar.

The term intracranial refers to the fact that the source of pain lies within the skull. Three types of intracranial pain can be identified: i) traction; ii) inflammatory; and iii) vascular. The first two varieties are ominous and often signs of serious disease. Fortunately, they are fairly rare. The intracranial vascular headache is usually quite benign.

Traction headache is caused by the swelling of lesions within the skull which exert pressure on pain sensitive structures. These lesions include tumors, hematomas, and abcesses. Inflammatory headaches result from inflammation of the outer membranes of the brain and spinal cord (meningitis) and surrounding blood vessels. Hemorrhaging under or within these membranes can also induce headaches of this type.

The pain of intracranial vascular headaches is caused by excessive vasodilation of the cerebral blood vessels. This sort of headache has been experienced by many in the form of a hangover following excessive alcohol intake. Ethyl alcohol is a potent vasodilator, as is at least one of its byproducts, acetylaldehyde. It is not fully known, however, whether the vasodilation associated with hangover is caused by the alcohol itself, its byproducts, or histamine, another common component of many alcoholic beverages (Lance, 1978; Ryan and Ryan, 1978). Intracranial vasodilation may also be produced by CO_2 retention, fever, hypoglycemia, and hyperthyroidism. Very few headaches of this type are potentially serious.

Extracranial headache, or headache stemming from a source outside the skull, is by far the most common type of head pain. The two main classes are muscle contraction headache and vascular headache. If the ubiquitous use of headache tablets is any indication, few of us have escaped an attack of muscle contraction headache. This condition is often referred to as a "tension" headache, since it is usually caused by

emotional strains, fatigue, or stress. The pain is generated by the prolonged contraction of the skeletal muscles of the head and neck. Muscle contraction headaches are generally episodic and vary widely between individuals in terms of intensity, frequency, and duration. Approximately 75% of the chronic sufferers are women.

The last major type of head pain is the extracranial vascular headache, in which pain is produced by the distension of scalp arteries. The common name for most afflictions of this sort is *migraine*. The term migraine is derived from the Greek word *hemicrania*, referring to the tendency for the pain to be confined to one half of the head, although it occasionally may occur bilaterally or across various parts of the face, neck and scalp. The types of migraine are many and varied, but they do tend to exhibit many of the same symptoms (Table 3.1). The attacks are generally episodic and recurrent; neurological disturbances often occur, upsetting sensory capacities; gastrointestinal aggravations are prevalent.

The underlying cause of migraine is not well understood, but the mechanisms by which migraine manifests itself are no secret. The initial phase of an attack is characterized by intense vasoconstriction of the cerebral arteries, causing a decrease in cerebral blood flow and resultant hypoxia (Skinhój, 1973). Some 10–30 minutes thereafter, vasodilation of the scalp, or extracranial, arteries occurs, resulting in throbbing head pain. Following this initial vasodilation, the vessels become edematous as the vessel walls become engorged with fluid (Figures 3.1 and 3.2).

Migraine tends to be more prevalent in women than in men. Various studies have shown that the proportion of female sufferers is likely between 60% (Selby and Lance, 1960) and 75% (Lance and Anthony, 1971; Oleson, 1978). In young children, however, it appears that about 60% of migraine cases are boys (Prensky, 1976). Most patients suffer their first migraine attack before the age of 20 (Figure 3.3). Over 40, the onset of migraine is very rare.

Selby and Lance (1960), in observing cases at a neurological clinic, found that the average bout of migraine lasted less than 24 hours, although they can extend for several days (Figure 3.4). Over half of the patients experienced less than 5 attacks per month (Figure 3.5).

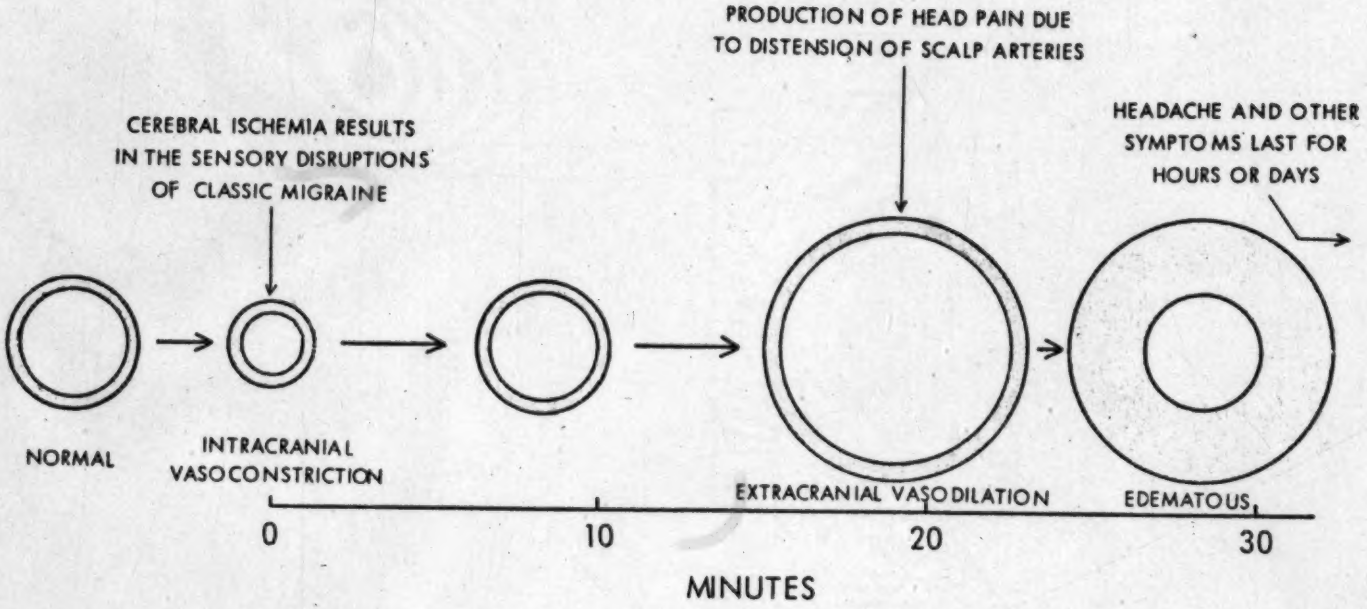


Fig. 3.1: Typical activity of the cranial arteries during a migraine attack. The relative sizes depicted are arbitrary.

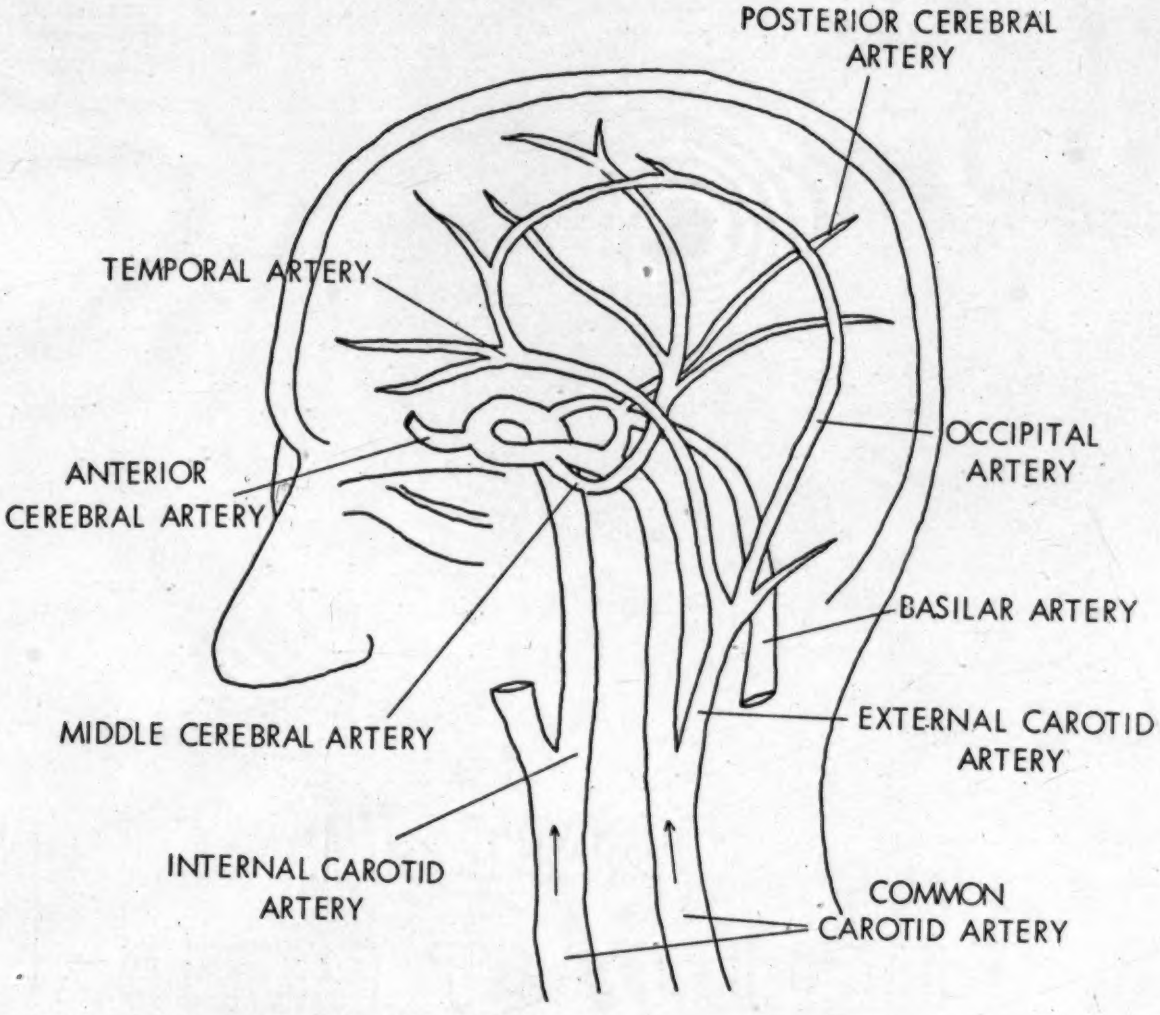


Fig. 3.2: The major arteries of the head.

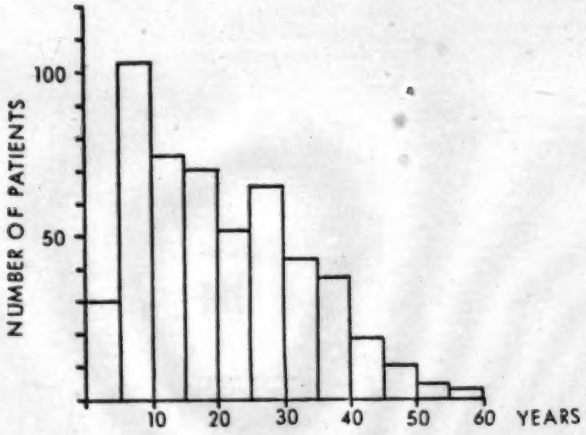


Fig. 3.3: The age of onset of migraine.
(After Lance, Curran and Anthony, 1965)

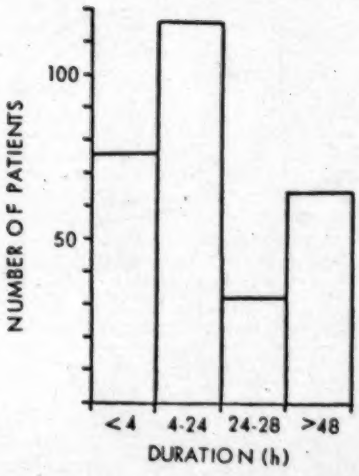


Fig. 3.4: Average duration of migraine attacks. (After Selby and Lance, 1960)

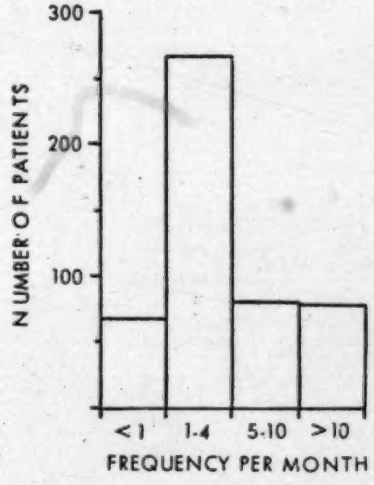


Fig. 3.5: Frequency of migraine attacks in patients attending a neurological clinic. (After Selby and Lance, 1960)

Table 3.1: Symptoms accompanying migraine attacks in 500 patients. (After Raskin and Appenzeller, 1980)

Symptoms:	Percentage affected:
Nausea	87
Vomiting	56
Diarrhea	16
Photophobia	82
Visual disturbances	36
----fortification spectra	*--10*
----photopsia	*--26*
Parathesias	33
Scalp tenderness	65
Lightheadedness	72
Vertigo	33
Alteration of consciousness	18
----seizure	*--4*
----syncope	*--10*
----confusional state	*--4*

A disposition towards migraine appears to be a familial feature. A family history of migraine is found in about 50 to 60 % of patients (Lance and Anthony, 1966). One female subject in the present study submitted a list documenting migraine ancestry in her family spanning five generations. Interestingly, all of those who acquired the affliction were female.

B. Pain Production in Migraine

Migraine is distinguished from other types of head pain in that the pain that is experienced during an attack originates from the extracranial (and possibly, in a small part, intracranial) vasculature. Graham and Wolff (1938) substantiated this theory when they observed that the severity of headache increased with an increase in the amplitude of pulsation in the scalp arteries. Furthermore, the injection of ergotamine tartrate, commonly used in the treatment of migraine, decreased pulsation by 50% and relieved the headache. During the neurological disturbances preceding the onset of a migraine headache, pulsation of the scalp arteries is at its lowest. The pulsation increases on the affected side with the onset of pain (Tunis and Wolff, 1953).

Perhaps the most distressing aspect of this vascular theory is the fact that cranial vasodilation is a common occurrence and is definitely not a painful experience. Exposure to heat produces marked vasodilation, yet results in no pain. Obviously, certain physiological functions triggered during migraine act to increase pain sensitivity within the scalp vasculature. Several theories exist as to why this may be so, and they are by no means mutually exclusive. It is likely that there are two or more interrelated mechanisms that stimulate head pain during a migraine attack.

Wolff (1972) hypothesized that in addition to vasodilation, there occurs on the afflicted side, a local sterile inflammation, during which a certain substance or substances, builds up within the arterial walls to lower pain thresholds. Specimens taken from the head during headache attacks yielded a protein that had previously been unidentified. This substance was labelled *neurokinin*. The amount of neurokinin found in the specimens was closely related to the intensity of the attack. Furthermore, administration of ergotamine tartrate produced relief from headache and a diminished concentration of neurokinin. Non-migrainous vasodilation such as a response to

hyperthermia, does not cause the release of neurokinin (Chapman, *et al*, 1960). Wolff also detected the presence of a neurokinin-forming enzyme (NFE) during migraine attacks. It seems likely, therefore, that neurokinin and the enzyme NFE are significant humoral agents in migraine's pain mechanism.

Rapid changes in the calibre of large blood vessels during the vasodilatory phase of migraine may also produce pain (Lance, 1978). If the capillaries fail to dilate as quickly as the larger vessels, blood begins to accumulate, causing the large vessels to be come over-distended. This may explain why many patients exhibit a pale complexion despite excessive blood flow in the temporal arteries. The administration of substances causing the dilation of smaller blood vessels has been shown to relieve migraine headache (Lund, 1957).

Another possible pain mechanism is simply the pressure of distended arteries on adjacent pain sensitive structures (Ryan and Ryan, 1978). Large blood vessels are more densely innervated than smaller ones and are therefore more sensitive to pain. Ray and Wolff (1940) provoked throbbing headaches by repeatedly distending and collapsing the superficial temporal artery. Nausea was also induced in some patients, effectively simulating the outstanding characteristics of a migraine attack.

Pain from the temporal artery and its branches is mediated by the trigeminal nerve (Figure 3.6). The occipital nerve transmits pain sensations from the posterior extracranial vessels. Because these two nerves connect at the same cells in the upper spinal cord, it is possible for pain in the neck to be referred to the forehead and vice versa. The vagus and glossopharyngeal nerves are also significant pathways in the transmission of head pain.

C. Migraine and its Variants

The Research Group on Migraine and Headache (1969) defined two forms of typical migraine,classic and common, and several atypical forms. A description of these follows.

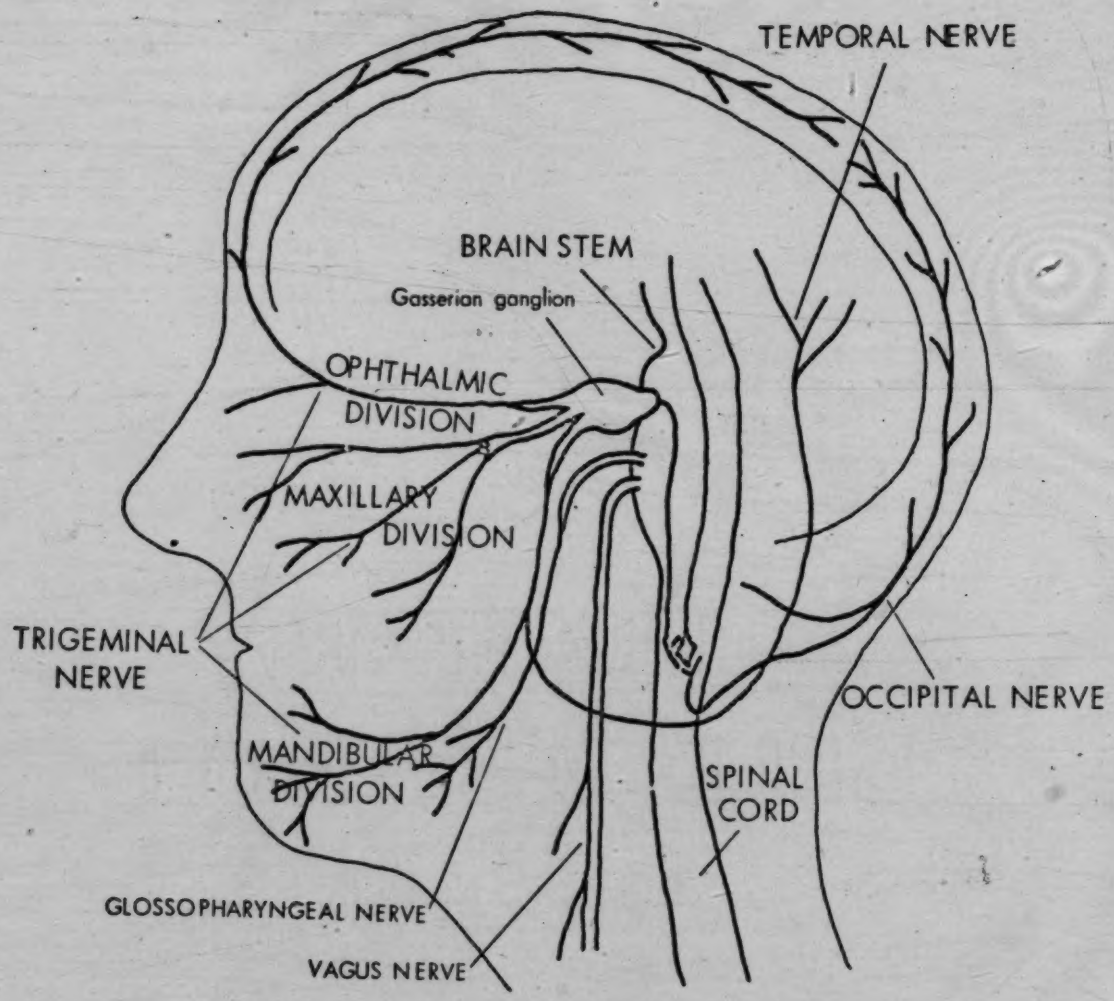


Fig. 3.6: The main nerves of the head.

Classic migraine:

Classic migraine's most distinguishing symptoms are the visual and other neurological disturbances felt just prior to the onset of headache. Some of the most common types of visual images are "fortification spectra", or bright castellated lines across the field of vision similar to an overhead view of the walls of a fort, and photopsia, in which stars of light appear to be falling through the field of vision. Other common visual disruptions include double vision, scintillating scotomas and darkening of portions of the visual field. Other sensory disturbances include dizziness, confusion and changes in auditory perception. Following one or more of these symptoms, unilateral head pain and nausea set in.

The neurological symptoms of classic migraine are believed to be the result of a significant reduction in cerebral blood flow due to vasoconstriction. Skinhøj (1970) estimated blood flow deficits of up to 50% in affected areas. Lance (1978) feels that it has been well proven that ischemia, or deficient blood supply, in the cortex or brainstem is the cause of the focal neurological symptoms of classic migraine. It is also possible for prolonged ischemia of this sort to result in permanent damage, such as impairment of vision. Guest and Woolf (1964) even reported a death attributable to cerebral infarction during the vasoconstrictive phase of migraine.

Common migraine:

As the name implies, common migraine is the most frequently encountered variety of extracranial vascular headache (Lance, 1978). It differs from classic migraine in that the neurological disturbances are absent. Cerebral vasoconstriction does occur in common migraine, but it is apparently of insufficient intensity to cause sensory disruption. The headache itself is usually unilateral, but can be bilateral on occasion. Symptoms such as nausea, vomiting and photophobia that are present in classic migraine are also characteristic of common.

It is quite possible for the sufferer of common migraine to experience the occasional neurological disturbance, just as classic migraine patients will sometimes experience only an attack of headache with no accompanying sensory disruptions.

Atypical forms of migraine:

Cluster headache (migrainous neuralgia) is an affliction that derives its name from the tendency for the pain to come in bouts or clusters of brief, but intensely painful headaches, usually once a day. Often these episodes will last for several weeks and then fail to recur for years. Unlike the more typical forms of migraine, cluster headache is most commonly found in men. Lance (1978) estimates the male dominance in the order of 3-6:1. The incidence of cluster headache is about 2-9% that of migraine (Friedman, 1969).

The pain of cluster headache is usually felt behind one eye and about the cheek. The headaches within one cluster almost always strike on the same side. Frequently, the attacks are nocturnal. Associated symptoms include tearing (lacrimation) in the affected eye and a stuffy or runny nose (rhinorrhea).

Some of the rarer migraine variants are as follows. *Facial migraine*, also called "lower-half headache", is a disorder is characterized by facial pain around the eye or across the cheeks. The attacks are generally less painful than typical migraine, but can last much longer. *Ophthalmoplegic migraine* is a rare form of migraine in which pain around the eyes is followed by paralysis of the extra-ocular muscles, resulting in a paralytic drooping of the upper eyelid and restricted eye movement. The ophthalmoplegia usually outlasts the headache by several days, but it may persist for as long as two months (Cruciger and Mazow, 1978). In *hemiplegic migraine*, the most overt symptom is a temporary paralysis of one half of the body. This may occur prior to the onset of headache and then clear up rapidly or it may persist for days, or even months, after the headache has disappeared. In the latter group, there is usually a strong family history of attacks of this sort (Wolff, 1972). *Basilar migraine* is caused by a reduction in the flow of blood through the basilar artery, causing ischemia in the brain stem. Symptoms include vertigo, reduction in muscular coordination, visual disturbances and fainting. The headache is most commonly across the back of the head.

Other types of migrainous disorders include *retinal migraine*, in which loss of vision is experienced in one eye, and *abdominal migraine*, characterized by abdominal pain. *Complicated migraine*, a somewhat ambiguous term, generally refers to patients who suffer permanent neurological damage following an attack. Some use the term

simply to refer to those with extremely pronounced focal neurological disruptions during a migraine episode (Bruyn, 1968).

D. The Migraine Personality

One commonly held belief about migraine is that sufferers tend to possess certain personality traits, that is, there is an identifiable "migraine personality". Ryan and Ryan (1978) state that characteristics of the migraine personality include a superiority complex, optimism, extreme ambition and a meticulous attention to detail. They tend to be perfectionists and will keep going even under the extreme duress imposed by a severe attack of migraine. Alvarez (1959) came to the conclusion that migrainous women typically possessed "a small trim body with firm breasts", and that they were of "quick eager mind and much social attractiveness". However, this view of a single migraine stereotype has become a point of contention. Many migraine specialists indicate that the emotional and psychological backgrounds of migrainous patients is so broad that there can be little or no classification (Sacks, 1970). Henryk-Gutt and Rees (1973) found no evidence of an obsessional or meticulous migraine stereotype in controlled studies. Bille (1962) discovered no significant personality differences between migrainous school-children and their peers. One possible reason for the belief that migraine most commonly afflicts the intelligent and the upper class is that it is these people who are more likely to consult a physician about the problem (Waters, 1975). It is also quite possible that obsessional personality traits may be more the result of migraine and its discomfort than the cause.

E. Migraine Triggers

The list of factors that have been mentioned as migraine precipitants is long and varied (Table 3.2). Given the proper stimulus, Lance (1978) feels that anyone can succumb to a migraine attack and it is likely that chronic migraine sufferers have a lower threshold to certain stimuli.

This is why the list includes many seemingly innocuous items, including weather. Because migraine sufferers do exhibit an increased sensitivity to many external stimuli, they respond clinically to weather changes which do not otherwise have any apparent effects

Table 3.2: Some common precipitating factors in migraine. (After Raskin and Appenzeller, 1980)

Stress and worry	Lack of sleep
Menstruation	Hunger
Oral contraceptives	Head trauma
Glare, dazzle	Certain foods
Physical exertion	*---chocolate*
Fatigue	*---wine and spirits*
Weather changes	*---dairy products*
Excessive sleep	*---citrus fruits*

on the majority of people. This same principle extends to the relationships between weather and other ailments.

Stress and anxiety are the most commonly cited migraine triggers. The source of stress can arise from factors such as noise, glare, exhaustion and innumerable others. Perhaps surprisingly, relaxation is also deemed to be a potential trigger. The phenomenon known as "weekend headache" has been documented by Gomersall and Stuart (1973) who found a significantly higher number of attacks on Saturday than on any other day. Sudden relaxation may trigger physiological changes. Raskin and Appenzeller (1980) observed that exhilaration, particularly falling in love, yielded a notable improvement in the migrainous condition. Usually, however, relapses occurred and the attacks resumed eventually. General Ulysses Grant apparently experienced a virtually instantaneous recovery from a severe bout of migraine once informed of General Lee's desire to surrender his Confederate forces to end the American Civil War (Jarcho, 1967). Thus, the point is well taken that the psychological environment of the sufferer has an important role in migraine.

Probably the most controversial migraine precipitant, and one which is very frequently quoted, is diet. Certain vasoactive amines and other compounds found in many foods may possibly have deleterious effects on the migraine patient. Chocolate, alcoholic beverages, cheese and citrus fruits are the most common foods associated with migraine (Smith, *et al*, 1970). Most attention has been focussed on the substance tyramine, a naturally occurring amine that acts to increase blood pressure and cause the

release of noradrenaline. Hanington (1967) observed migraine attacks in patients who had ingested tyramine-rich foods, especially dairy products. A subsequent study by Hanington, Horn and Wilkinson (1970) found similar results using tyramine and placebo capsules. However, many further studies have failed to duplicate these results and have generally concluded that tyramine is not a significant migraine trigger (Ryan, 1974; Forsythe and Redman, 1974; Shaw, *et al*, 1978). Thus, the role of tyramine in migraine remains largely unresolved.

The compound phenylethylamine, present in chocolate and red wine among other things, has also been implicated as a dietary trigger. Sandler, *et al* (1974) concluded that a cause and effect relationship did exist between PEA and migraine. On the other hand, however, Moffett, *et al* (1974) were unable to produce a significantly higher number of headaches with chocolate than with a placebo.

Other possible dietary precipitants of migraine include the "Chinese Restaurant Syndrome", apparently triggered by the large quantities of monosodium glutamate used for seasoning (Kwok, 1968). "Hot dog headache" is another variety that has been linked to the nitrites within the meat (Henderson and Raskin, 1972).

Hunger has also been linked to migraine (Blau and Cumings, 1966). Low blood sugar levels stimulate rapid turnover of brain serotonin (Curzon, *et al*, 1972) and this may be of significance. Any effects that low blood sugar may have are almost certainly indirect (Pearce, 1971).

The female reproductive cycle has been consistently associated with migraine. Lance (1978) states that 60% of women patients can relate the periodicity of their attacks to the menstrual cycle. Furthermore, pregnancy acts to alleviate migraine in about 60% of women. Many migrainous women who have had hysterectomies but retained their ovaries still experience attacks every 28-30 days (Ryan and Ryan, 1978). Somerville (1972a, 1975) discovered that premenstrual migraine tends to occur as levels of both estrogen and progesterone are falling, but that it is the withdrawal of estrogen that is significant. Since estrogen levels also fall dramatically in the middle of the cycle, this could account for complaints of mid-cycle migraine.

There is an apparent relationship between migraine and contraceptive pills. Most women fit into two groups. There are those whose headaches are aggravated, either in

frequency or severity, by oral contraceptives, while some women notice no change (Ryan and Ryan, 1978). Only a very small number experience an alleviation of attacks. Greene (1975) found a correlation between migraine frequency and estrogen concentration in contraceptives. Low doses of estrogen can be used successfully without aggravating migraine.

Welcome relief from migraine is often found during pregnancy. Somerville (1972b) observed that 24 of 31 migrainous women in one study had a remission of migraine during pregnancy. Unfortunately, the profuse biochemical changes that appear during pregnancy readily obscure why this may be so.

There are many other potential migraine precipitants. Dalessio (1974) observed "exertion migraine" that appeared after intense exercise in susceptible persons. "Footballer's migraine" has been seen in soccer players after "heading" the ball too often (Matthews, 1972). Other types of head trauma have also been implicated in migraine. Naturally, a relationship between migraine and weather has also been frequently mentioned and will be discussed at length later.

F. The Pathogenesis of Migraine

It is well established that pronounced vascular changes occur during migraine, accompanied by various epiphenomena. The vascular activity of migraine is biphasic with cerebral vasoconstriction being followed by extracranial, and possibly cerebral, vasodilation. Subsequently, local edema appears at the site of the headache.

The major stumbling block in the clinical analysis of migraine is its mysterious etiology. Its underlying cause and the mechanisms that produce the symptoms experienced by the patient are still largely unknown and the subject of much conjecture. Unfortunately, research is complicated by the fact that there is no comparable animal model and that attacks within individuals are intermittent and widely variable. Furthermore, the wide variety of symptoms and the numerous trigger factors seem to indicate the presence of several interrelated mechanisms.

There are two basic hypotheses about the mechanism of migraine. It may be a central disorder of the vascular regulatory mechanism, resulting in poor control of the tone and calibre of blood vessels. It may also be the result of dysfunctional biochemical

regulation, as evidenced by several vasoactive hormones that have been intimately linked to the migraine process. It is likely a combination of both, involving the autonomic nervous system and certain humoral agents. Some of the more important migraine pathogens will now be discussed in detail.

Serotonin:

The most widely implicated humoral agent in migraine pathogenesis is the vasoactive amine serotonin (5-hydroxytryptamine). It is synthesized in the intestinal wall where it is picked up by blood platelets. Aside from the intestine, most serotonin is bound to platelets; smaller amounts exist in the brain and traces remain free in blood plasma.

Serotonin tends to constrict large blood vessels and dilate smaller ones; this is the opposite of what happens in migraine. Therefore, one might expect decreases in blood serotonin to be associated with migraine attacks. This relationship has been consistently demonstrated (Lance, 1978).

Platelet-bound serotonin tends to decrease markedly during the onset of a migraine headache (Anthony and Lance, 1975; Somerville, 1976). Furthermore, the presence of a serotonin-releasing factor has been detected in the blood during migraine. This enzyme causes serotonin to be released from blood platelets, causing a decrease in serotonin levels (Anthony, *et al*, 1968; Dvilansky, *et al*, 1976). This releasing factor is not present in normal blood. Another study by Anthony, *et al* (1967) found that a drop in platelet serotonin levels was not a general response to pain and stress, but was specific to migraine. Urinary concentrations of serotonin and 5-HIAA, its main metabolite, increase during an attack (Sicuteri, *et al*, 1961).

Platelet serotonin can be decreased by the intramuscular injection of reserpine. In non-migrainous subjects, this usually results in a dull headache, while most migrainous patients experience a typical migraine attack. Subsequent injections of serotonin can alleviate these headaches by increasing platelet-bound serotonin (Kimball, *et al*, 1960; Anthony, *et al*, 1967).

The aggregability of platelets, or their tendency to clump together, is a measure of their serotonin content. Lower levels of platelet serotonin mean increased platelet

aggregation. Hilton and Cumings (1971, 1972) found that serotonin-induced platelet aggregation is greater at all times in migrainous subjects than in normal subjects, indicating a reduced capacity for migrainous platelets to retain serotonin.

Hormonal circuits involving serotonin can also be found in many other physiological functions. Serotonin is an important neurotransmitter (Curzon, 1978) and has also been implicated in sleep, mood and thermoregulation (Edelman, *et al*, 1977; Myers and Waller, 1978). Decreases in brain serotonin levels also tend to lower pain thresholds (Herz and Blazig, 1978). The fact that serotonin performs a plethora of activities in various physiological systems seems consistent with the wide variety of symptoms present in migraine.

The major hypothesis still, however, revolves around the vasoactive properties of serotonin. It is apparent that a serotonin-releasing factor appears in the blood at the onset of migraine resulting in the sudden withdrawal of platelet-bound serotonin. Thus, it is assumed that there is a consequent loss of vascular tone. There are, however, several objections to the theory. There is no evidence to confirm that serotonin is significant in regulating arterial tone during migraine. Furthermore, why are only the cranial arteries affected when platelet serotonin levels decrease in other areas as well? Obviously, the consistent correlations between migraine and serotonin implicate a profound link between the two, but the precise relationship is far from clear.

Prostaglandins:

Prostaglandins are long chain fatty acids synthesized in all parts of the body. They have significant effects on cerebral circulation with PGE_1 being a potent dilator and PGE_2 a potent constrictor.

A study in Scandinavia reported that the intravenous injection of prostaglandin E_1 triggered typical migraine attacks in non-migrainous volunteers (Carlson, Ekelund and Oro, 1968). The subjects developed headache, abdominal pain and nausea; two subjects even reported flashing visual disturbances prior to the onset of unilateral headache. However, Anthony (1976) noted no changes in PGE_1 concentration in the blood during migraine attacks.

In studies on monkeys, Welch, *et al* (1974) found that PGE_1 induced marked extracranial vasodilation and loss of central vascular control. Furthermore, at high doses, there is a reduction of cerebral blood flow, likely due to excessive blood flow into the external carotid artery.

Serotonin is closely linked to prostaglandins as it acts as a PG-releasing factor (Alabaster and Bakhle, 1970). It is likely, therefore, that prostaglandin release is secondary to the release of serotonin (Anthony and Lance, 1975). The role of PGE_1 in migraine may very well be confined to contributing to the head pain at the site of arterial inflammation.

Histamine:

Histamine has long been thought to be involved in migraine. Injection of histamine can provoke a severe, but brief, throbbing headache. However, unlike migraine, this headache can be blocked by the prior administration of antihistamines (Östfeld, *et al*, 1957).

Histamine levels increase during migraine and are considerably higher after an attack than before it (Anthony and Lance, 1971). It is unlikely that histamine is significant in stimulating the onset of migraine, but it may have a local pain-provoking effect at the site of arterial inflammation (Curzon and Hilton, 1975).

Central vasomotor dysregulation:

Examination of the vascular responses in migraine sufferers indicates that migraine may be the result of a central disorder that inhibits proper regulation of the vascular system (Raskin and Appenzeller, 1980). Changes in posture can induce transient cerebral ischemia in migraineurs (Raskin and Knittle, 1976). They also appear to show slower vascular responses to hot and cold stimuli (Appenzeller, *et al*, 1963; Appenzeller, 1978). Unfortunately, other studies have found conflicting results (Macmillan and Hockaday, 1966; French, *et al*, 1967).

Lance (1978) states that there is no conclusive evidence to support the theory of dysfunctional central vasomotor control. Raskin and Appenzeller (1980), however, feel that the idea is viable. At present, it remains in limbo.

Conclusions:

Wolff (1972) and Dalessio (1980) view migraine as a "cerebral vasospasm", generated by a migraine sufferer's hyperreactivity to external and internal stimuli. Thus, any factors that are perceived by the brain and central nervous system as threatening or noxious trigger an excessive reaction within the vascular system. This reaction which is manifested as migraine, involves both the central and peripheral vasomotor mechanisms as well as a sterile inflammatory reaction within certain arterial walls. It is the latter component that produces headache. Lance (1978) agrees with this assessment. He describes migraine as a "hypersensitive protective mechanism for preserving the integrity of the brain against any sudden change in the internal or external environment" (p. 177).

It is obvious that migraine is a response to various internal and external stimuli. Transmission of these stimuli to the vasomotor centers is via the autonomic nervous system, certain humoral agents, such as serotonin, and/or immune mechanisms. It is still not known which of these is most significant. Sicuteri (1976) suggests that migraine is the result of a central serotonin deficiency that acts to lower pain thresholds.

It is very possible that the headache associated with migraine is secondary to the vascular responses that occur within the brain. The direct result of certain stimuli is a neurovascular reaction that alters cranial blood flow. Certain biochemical changes that result from this reaction may provoke the headache that is usually the most overt and aggravating of all migraine symptoms (Lance, 1978; Dalessio, 1980).

Any impact that weather may have on migraine is undoubtedly related to the lower threshold of resistance that sufferers have to their external environment. Stress imposed by weather, be it a change in air pressure or an increase in temperature, may be sufficient to provoke an excessive physiological reaction resulting in a migraine attack. This will be discussed more fully in Chapter 8.

IV. A Review of the Literature on Weather and Migraine

"No cheerful breeze this sullen region knows,
The dreaded East is all the wind that blows.
Here in a grotto, sheltered close from air,
And screened in shades from day's detested glare,
She sighs for ever on her pensive bed,
Pain at her side and Megrim at her head."

Alexander Pope
The Rape of the Lock
Canto No. 4
1714

A common complaint among migraine sufferers is the aggravating effects that certain weather conditions have on their health. These conditions most commonly include falling barometric pressure, glare, heat, cold, thunderstorms and specific local winds, such as the Sharav of Israel and the European Foehn.

A. Historical antecedents

The above quote by Pope indicates an awareness that many of our predecessors had of the influence that weather can exert on migraine. He alludes to two well-documented migraine triggers: i) the wind he describes as "the dreaded East" sounds remarkably like the hot, dry Sharav that descends on Israel from the deserts to the east, provoking misery and ill-health in much of the population (Sulman, 1976); and ii) "day's detested glare" is a factor that seems to induce attacks of migraine in about 30% of those susceptible (Pearce, 1971). It is fairly easy to find other historical references to a weather-migraine connection. The eighteenth-century physician, Charles Lepois, wrote an autobiographical account of his migraine attacks and attributed them to changes in climate, westerly winds and rainstorms (Dalessio, 1968). Robert Scott, the Antarctic explorer, consistently suffered attacks 10-12 hours before a storm (Wilson, 1972).

B. Weather-migraine studies

S.W. Tromp (1963), a biometeorological pioneer, felt that "forms of migraine are most common during drastic changes in weather, just before heavy snowfall, thunderstorms, and so forth" (p. 544). In his most recent book, *Biometeorology* (1980), he adds other possible factors, including frontal passage and sudden changes in light intensity.

The most comprehensive study on weather and migraine to date was performed by Gomersall and Stuart (1973) in Aberdeen, Scotland. During the study period (November, 1969, to May, 1970), 55% of the subjects experienced at least one attack that they felt could be attributed to weather. In total, however, these only accounted for 2.5% of all attacks. Their most significant conclusions reported that there was a *decreased* incidence of attacks during periods of both low and falling pressure. Furthermore, attack frequency *increased* as the atmospheric pressure rose. These particular results, however, remain unsubstantiated. Other findings of note by Gomersall and Stuart include a higher frequency of attacks during periods of low relative humidity, the effect of glare as an aggravating factor in migraine attacks, and the onset of migraine in some patients 10–12 hours prior to thunder or snow storms. A small percentage of subjects were also sensitive to atmospheric cooling.

Barrie, *et al* (1968), during a two-month study in and around London, found no relationship between migraines and barometric pressure, temperature, rainfall, sunshine or wind speed and concluded that weather was not significant. A five-year study in Bavaria by Kugler and Laub (1978) uncovered no correlation between migraine and temperature, pressure, humidity or ionization.

C. Glare and bright light

Glare and bright light is mentioned as a precipitant by about 30% of migraine sufferers (Pearce, 1971). Golla and Winter (1959) produced a migrainous reaction in susceptible subjects using flashing lights. Rawnsley and Loudon (1964) cite bright sunshine as a major cause of headache on the remote Atlantic island of Tristan da Cunha. Even in children, glare is recognized as a major factor, from sources such as bright sunshine reflecting off snow or the sea (Bille, 1962).

D. Barometric pressure

Lance (1975, 1978) mentions that changes in barometric pressure may provoke migraine. It was also very frequently cited as a potent trigger factor by the subjects in this study. Some patients seem to possess what Sacks (1970) calls "meteorological clairvoyance" and claim to be able to predict imminent storms or changes in weather. Very often, these individuals feel that it is the falling atmospheric pressure that precedes these storms that aggravates their migraine.

No study into the migraine-weather connection *per se* has been able to determine a connection between falling pressure and increasing migraine frequency or severity. In fact, results to the contrary were noted by Gomersall and Stuart (1973) who observed an increase during rising pressure. However, pressure extremes more severe than those experienced during synoptic-scale disturbances have been shown to affect otherwise healthy individuals.

Sensitivity to very low barometric pressure can be seen in the peculiar affliction known as "mountain sickness". Exposure to the low pressure and reduced oxygen content of high altitudes can provoke numerous reactions, but the most common and severe is pronounced vascular headache (Sargent and Tromp, 1964; Dalessio, 1980). King and Robinson (1972) induced throbbing headaches in 30 healthy young males after exposure to simulated altitudes of about 4500 m. The severity of symptoms increased for the first 24 to 48 hours and then began to subside. Investigations by Appenzeller (1972) indicate that altitude sickness is unknown at elevations below 2500 m, but above 4000 m, it will appear almost universally in those who are unacclimatized. Anderson, *et al* (1965) reported a migraine-like syndrome that developed in four male subjects immediately after decompression from simulated depths of 20 to 40 m underwater. Engel, *et al* (1945) observed migrainous episodes in subjects 5 to 30 minutes after *descent* from a simulated altitude.

Relief of migraine using pressure treatments has been attempted by Tromp (1980) and Raskin (1979, personal communication). Tromp claims success in relieving serious cases of migraine by repeated exposures to low pressures (above 2000 m) and temperatures below 10°C. Raskin, on the other hand, used high pressure treatment (simulated depths of 30 m underwater) on 20 patients without significant success.

Thus, there appears to be some association between barometric pressure and vascular headache. Rapid and extreme changes (more than about 10 or 20 kPa) in either direction tend to aggravate. There are major difficulties, however, in assessing whether the pressure change is a direct causal mechanism or, as is more likely, indirect. It is probably a function of the change in the partial pressure of oxygen in the air. It must be remembered that these studies of mountain sickness involve far greater extremes of pressure than are ever experienced during atmospheric activity at any given altitude and are therefore subject to cautious interpretation in terms of the weather–migraine link.

E. Local winds

Certain local winds have long been considered to be unfavourable to both general health and migraine. The most notorious of these are the Sharav, or Khamsin, of the Middle East, and the Foehn that descends the northern edge of the Alps into the valleys of Switzerland, Austria and Bavaria (Sulman, 1976; Tromp, 1980). Apparently, Sigmund Freud commonly attributed his attacks of classic migraine to the Italian south wind, and precursor of the Foehn, the Sirocco (Sacks, 1970).

Intense analysis of the effects of the Sharav by Sulman and his colleagues indicates that about 20% of the adult population are sensitive to this phenomenon and display an increased incidence of clinical ailments prior to and during the Sharav (Sulman, 1971; Sulman, *et al*, 1970; Danon, Weller and Sulman, 1969; Danon and Sulman, 1969). About 43% of the Sharav–sensitive individuals are subject to what Sulman calls the Serotonin Irritation Syndrome. One to two days prior to the onset of the Sharav, there are measurable increases in the urinary output of serotonin and its main metabolite, 5–HIAA. Coincident with this is a syndrome characterized by migraine, allergic reactions, sleeplessness and other symptoms. This malady tends to continue for the duration of the Sharav, finally diminishing as "normal" weather begins to prevail. The reason proposed for causing this Irritation Syndrome is the measurable build–up of the total number of ions in the air, as well as an increase in the ratio of positive to negative ions (Robinson and Dirnfeld, 1963). The biologically unfavourable positive ions appear to stimulate the hyperproduction of serotonin by the hypothalamus.

The Foehn wind has long been associated with changes in both mental and physical health. One of the major symptoms of the so-called "Foehn disease" is migraine, although there are many others (Brezowsky, 1964; Sulman, 1976; Tromp, 1980). The mechanisms of Foehn disease are not well understood, however. Although symptoms tend to start appearing in the pre-Foehn stage, no build-up of ions has been detected. Furthermore, a wide range of meteorological conditions can accompany the Foehn at different times of the year, thereby precluding any easy explanations. As mentioned earlier, the Chinook in Western Canada has no well-documented effects on physical health. Most authors seem to feel it has an invigorating effect during the otherwise severe winter, but this has not been substantiated.

F. Weather phases

In addition to correlating migraine with individual meteorological parameters, several studies have analyzed the relationship between migraine and complete synoptic weather patterns. This has been accomplished using a system for classifying weather into different types, called *weather phases*. This scheme is described in detail in the following chapter.

Several studies in Germany have analyzed the migraine-weather phase connection. The weather associated with the passage of a warm front (phase 4) and, to a lesser extent, cold fronts (phases 5 and 6Z), has been consistently shown to produce an escalation in migraine frequency. Brezowsky (1964) found a marked increase in migraine incidence during phase 4 (Figure 4.1). Kugler (1972) detected a similar relationship between migraine frequency and phase 4 (Figure 4.2). Kugler and Laub (1978), however, observed phase 6Z to have the most unfavourable effects, although phases 4 and 5 also appeared to have an adverse impact on migraine (Figure 4.3). Both phases 1 and 2 (anticyclonic weather) consistently registered favourable effects. The results of these studies repeatedly demonstrate the adverse influence on migraine during phases 4, 5 and 6Z, and the largely beneficial influences during phases 1 and 2.

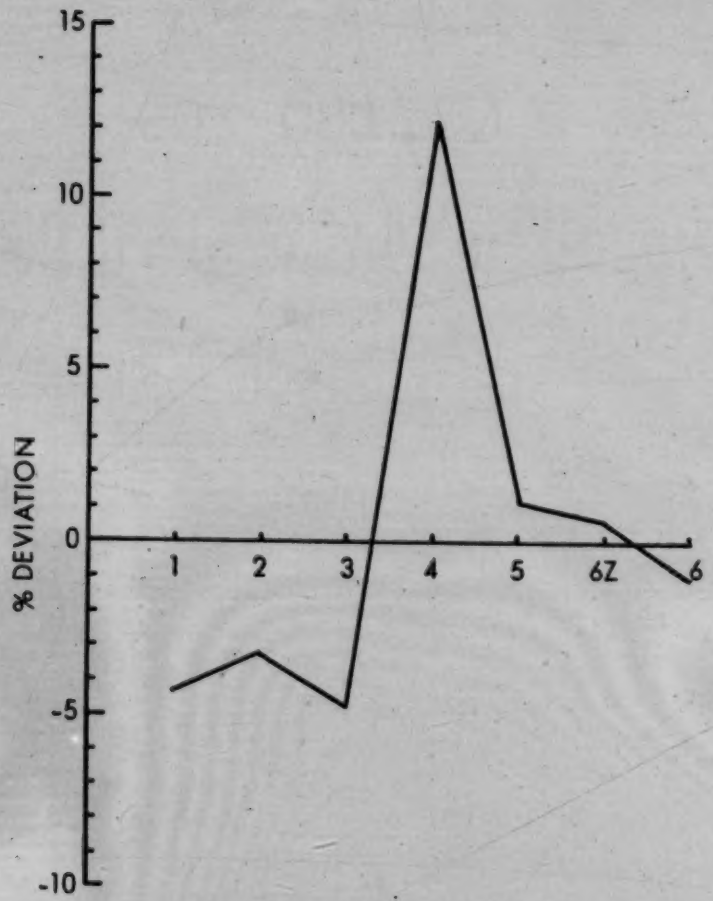


Fig. 4.1: Effects of weather phases on migraine
(After Brezowsky, 1964)

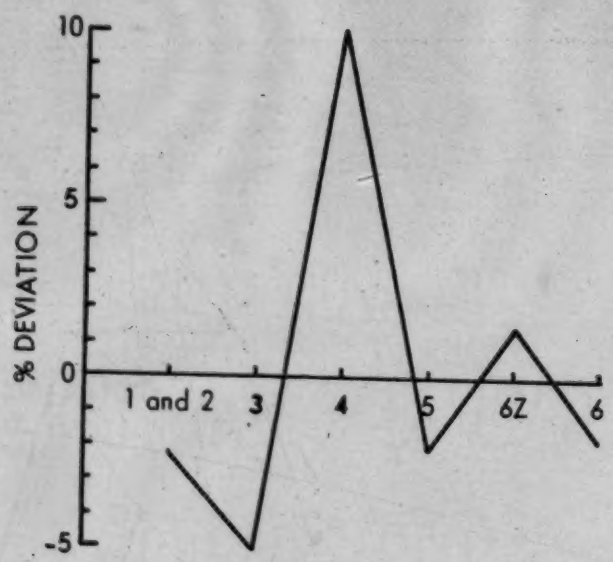


Fig. 4.2: Effects of weather phases on migraine (After Kugler, 1972)

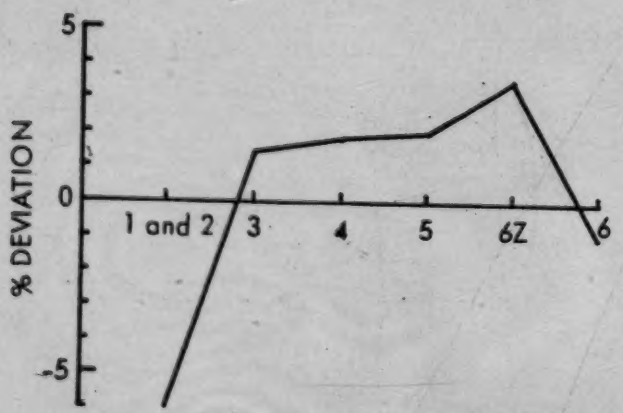


Fig. 4.3: Effects of weather phases on migraine (After Kugler and Laub, 1978)

V. Weather Phases

The concept of weather phases merits close attention. This classification of weather has been used extensively in biometeorological research in Europe with impressive results. The scheme is also used in this study. The results indicate that certain "phases" have significant effects on migraine.

Much of the early work in medical biometeorology was devoted to establishing correlations between specific ailments and individual meteorological parameters. Petersen (1938), for example, showed much interest in the effects of temperature and pressure on health. He made extensive use of graphs illustrating the relationships between a patient's progress and atmospheric trends. Very often, however, comparisons of medical data with simple meteorological elements yield no significant results (Tromp, 1963). This indicates that the association between weather and health is more complex than is immediately apparent. The strongest meteorological impact on health seems to be the result of certain weather conditions acting in concert, rather than individually.

This likelihood stimulated interest in devising some sort of technique whereby weather could be divided into various types of synoptic situations. A scheme was ultimately developed in Germany during the 1950's by Drs. Hans Ungeheuer and Helmuth Brezowsky. They called their model *weather phases*. By using specific criteria to define each phase, based largely on temperature and humidity, a systematic classification of weather types was introduced, allowing the examination of physiological and biological reactions to weather as a whole rather than as a set of individual constituents. The following discussion of their system is based largely on detailed works by Brezowsky (1960, in German; and 1964).

A. Rationale behind the scheme

The system of weather phases is basically a type of weather classification that is designed to be used as a productive biometeorological tool. Unfortunately, weather is not something that readily lends itself to categorization. Any attempt to do so necessarily leads to a certain amount of simplification, particularly because of the continuous nature of the atmosphere and the tremendous number of parameters to

consider. Because weather does not exist in discrete parcels, one encounters great difficulty in determining criteria for classification, where to designate boundaries between classes and how to deal with the inevitable transitional forms. The task is not an enviable one.

The approach adopted by Brezowsky, Ungeheuer and their colleagues was to use Bjerknes' model of mid-latitude circulation as a conceptual framework. The Bjerknes model, well known as the textbook example of mid-latitude atmospheric circulation, incorporates a traveling depression moving in a general easterly direction, steered by the westerlies aloft. In its simplest form, the depression and its attendant fronts form the boundary between various air masses, with warm air generally advancing from the south behind a warm front and cooler air pushing a cold front which trails the center of low pressure. The high pressure systems that surround the depressions constitute the different air masses.

Starting from this assumption, the model was divided into two major groups, the anticyclonic high pressure zone and the traveling depression. Further subdivisions could be made qualitatively, particularly around the depression, based on cold and warm fronts and the weather associated with each of them. Thus, an initial framework was developed.

Obviously, the qualitative criteria alone were insufficient for an adequate classification, mostly due to the large degree of subjectivity in separating the classes. A quantitative measure of some sort was essential in order to introduce an objective basis to the model. Ungeheuer decided to isolate temperature and humidity as two of the most important factors that distinguish weather conditions within the Bjerknes model. He came to this conclusion for several reasons. First, both temperature and humidity exert profound physiological effects, thus making them ideal for use as criteria in defining a classification scheme designed for biometeorology. Second, both are intimately affected by changes in atmospheric conditions. Variations in radiation, precipitation, wind speed and evaporation will all be reflected in the values of temperature and humidity. Surface advection will generally act to change all these parameters resulting in changes in both the air temperature and the dew point temperature. Thus, advection of different weather conditions can be determined in a quantitative sense by changes in both the wet and dry bulb temperatures.

The end result is an idealistic classification based on the temperature–humidity milieu of the atmosphere and the continuous zonal progression of low pressure systems across the mid–latitudes. Each class has its characteristic temperature and humidity structure resulting from the advection of air masses across the observing stations (Figure 5.1 and Table 5.1). Although temperature and humidity are the key criteria, other weather elements also help distinguish each phase, including sky condition, pressure tendency and wind direction.

The biological effects of the weather phases, according to Brezowsky, stem largely from the *change* of temperature and humidity due to the exchange of air mass type, particularly during the passage of warm and cold fronts. The magnitude of the impact on health of these alterations in the temperature–humidity environment appears to be a function of two factors: i) the size of the change, ie., an increase in the frequency of changes and/or their magnitude will cause an increase in biological impact; and ii) certain biological reactions will exhibit marked associations with particular types of weather or weather change.

B. Description of the phases

Although the weather phase model was developed in Bavaria for use in continental Europe, it also serves admirably for use in northeastern North America. Each of the phases possess similar characteristics in both regions. The only exception is the special European "Foehn" phase which is excluded due to the absence of a similar phenomenon in eastern North America. The result is a system of seven weather phases that was used in this study. A sequential description of the seven phases is as follows:

Phase 1: weather characterized by the cool, dry leading edge of an advancing high pressure system.

Phase 2: the center of this system, where the pressure is the highest, the sky is clear and the air is warm and dry.

Phase 3: the pressure begins to fall; however, the temperature increases and the humidity remains relatively low.

Phase 4: the pressure continues to drop and a warm front passes often bringing rain.

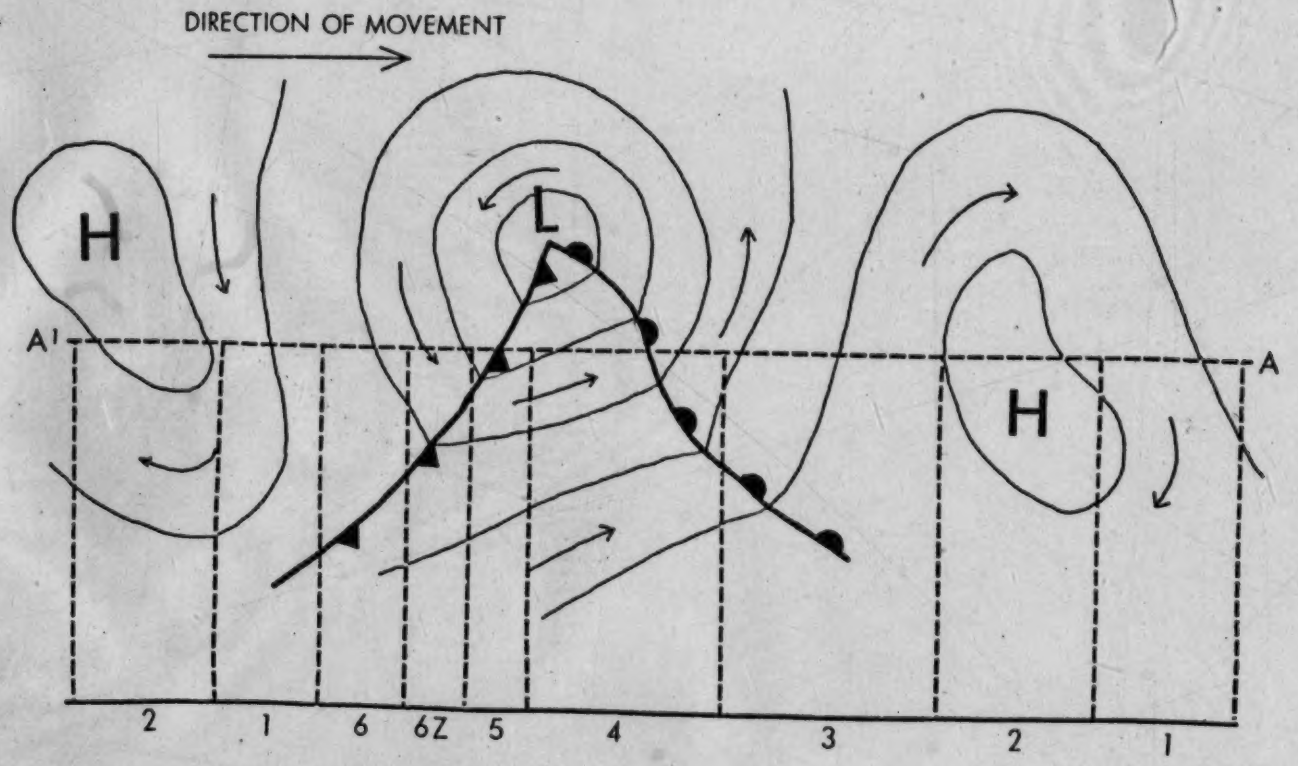


Fig. 5.1: Succession of weather phases through an idealized cross-section of a synoptic weather system along line A A'.

PHASE	1	2	3	4	5	6Z	6
Description of the weather	average nice weather	very nice weather	exceedingly nice weather	imminent change of weather	change of weather	completed change of weather	gradual clearing
	FAIR WEATHER			DISTURBANCES			FAIR WEATHER
Temperature-Humidity Environment	cool–mild dry	mild–warm dry	warm dry	warm front passage warm humid	cold front passage change to cooler–cold humid	cool–cold humid	cool dry
Pressure tendency	increasing	high and constant	decreasing	rapidly decreasing	at lowest value	rapidly increasing	increasing
Prevailing wind direction	N, NW	generally calm	S, SE, SW	S, SW, SE	changes sharply to west	W, NW, N	W, NW, N
Degree of biotropic irritation	BIOLOGICALLY FAVOURABLE		TRANSI-TIONAL	BIOLOGICALLY UNFAVOURABLE			FAVOURABLE

Table 5.1: A brief summary of the meteorological characteristics of idealized weather phases in Southern Ontario.

Both the dry and wet temperatures attain their highest values, resulting in the sultry, oppressive weather particularly common in northeastern North America during the summer months.

Phase 5: the cold front approaches and thick clouds develop, usually resulting in precipitation. The pressure drops to its lowest level during the frontal passage, when the temperature drops sharply and the wind shifts.

Phase 6Z: the cool, humid region which trails the cold front.

Phase 6: clearing skies, falling humidity and relatively low temperatures.

Phase 6 weather generally precedes the onset of phase 1.

Because this is an idealized arrangement, there will naturally be instances when the atmosphere fails to conform to the model. It is not necessary for the phases to always occur in the prescribed sequence. This system does, however, provide a fairly comprehensive classification system and it is not very often that weather conditions do not appear to fit any category.

Brezowsky divided the phases into two groups based on their biological effects, or biotropism. Phases 1, 2 and 6, comprising Group I, are considered to be periods of unperturbed weather and favourable biologically. Diurnal fluctuations of temperature and humidity follow a rhythmic pattern. Group II phases, consisting of 3, 4, 5 and 6Z, are associated with the advection of external air masses, and the diurnal periodicity of meteorological elements breaks down with the passage of fronts. These phases are deemed to be biologically unfavourable.

C. Biometeorological research using weather phases

Because weather phases provide an excellent framework for categorizing the various arrays of synoptic weather conditions, they are an important biometeorological tool. Brezowsky (1964) performed a comprehensive examination of several clinical ailments and relationships to weather in the Bavarian towns of Bayreuth and Bad Tolz. The results provided overwhelming evidence that phase 4 had profoundly deleterious effects on human health. Figure 5.2 illustrates the sharp rise in frequency of nine different ailments, including migraine, during phase 4 weather. Other biometeorological research has confirmed the adverse biotropy of phase 4; in addition to those listed in

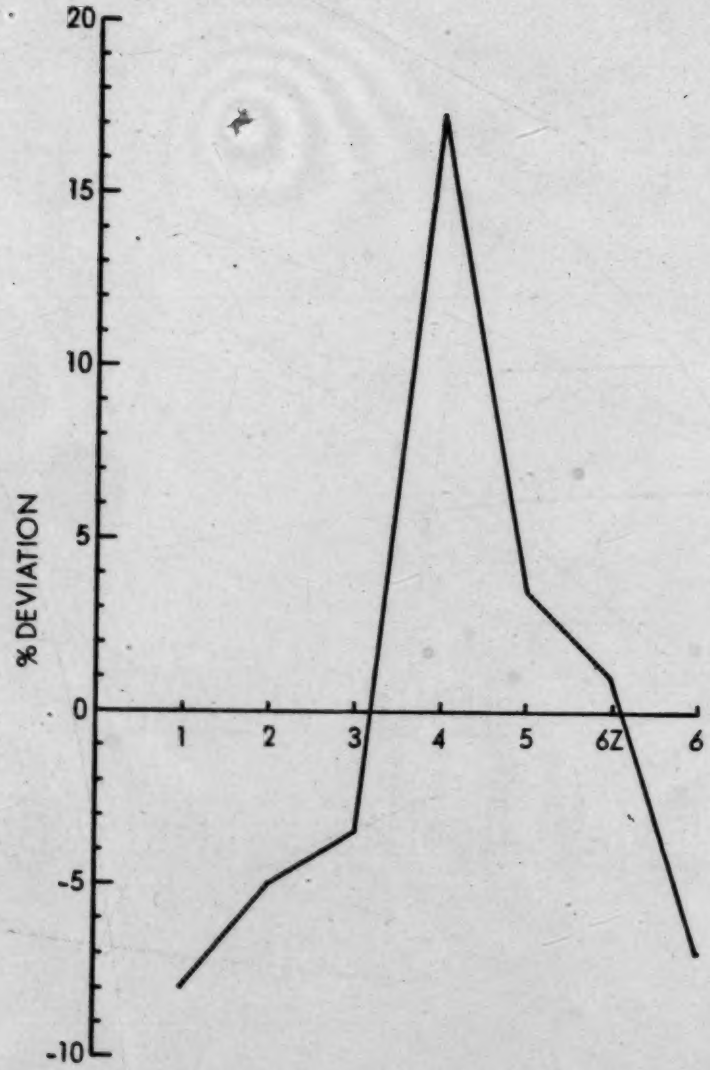


Fig. 5.2: Median distribution for nine clinical complaints (emboli, hemorrhages, asthmatic attacks, migraine, myocardial infarcts, colic, angina pectoris, attacks, osteoarthritic complaints, neuroma pain.) (After Brezowsky, 1964)

Figure 5.2, Tromp (1963), Kevan (1980) and Brezowský have documented increases in the frequency and/or the severity of the following medical disorders during the influence of phase 4 weather: stroke, thrombosis, thrombophlebitis, gastritis, meningitis, dyspnea (laboured breathing), bronchitis, diabetes and many more. Furthermore, accidents of all sorts tend to increase when phase 4 prevails. It is obvious that the physiological and pathological effects of phase 4 are powerful indeed. Unfortunately, the complexity of the factors occurring during each weather phase greatly hinders attempts to determine why this may be so.

In addition to the obvious physiological irritation exerted by phase 4, phases 5 and 6Z have also been found to have slightly aggravating effects. Conversely, phases 1, 2 and 6 are consistently associated with favourable qualities and a decreased incidence of most ailments. Phase 3 is generally accepted as possessing only a moderate degree of biotropy and essentially marks a transition between phases that are biologically favourable and those that biologically unfavourable.

D. Weather phases in Toronto, April to December, 1979

Weather phases in Toronto during the study period were determined using hourly meteorological data from Toronto International Airport and the *Daily Weather Maps* issued by NOAA. These two sources provided all the information necessary to assess the temperature–humidity environment in the Toronto region and the changes thereof, and made it a matter of comparative ease to distinguish the various weather phases.

The relative frequency of occurrence for each phase from April to December, 1979, is given in Figure 5.3. The southerly incursions of maritime tropical air characterizing phase 4 were the most common type. Phase 5 occurred least often, or at least had the shortest duration, due to the generally rapid movement of cold fronts. The ratio of Group II phases to Group I, or unfavourable to favourable, was about 1.5:1. In central Europe, this proportion is about 2:1, and this ratio will change depending on geographical location.

Each phase has a characteristic temperature–humidity environment. In Figure 5.4, the average temperature and dew point for each phase during the entire study period is illustrated. This gives a graphic representation of the quantitiative differences between

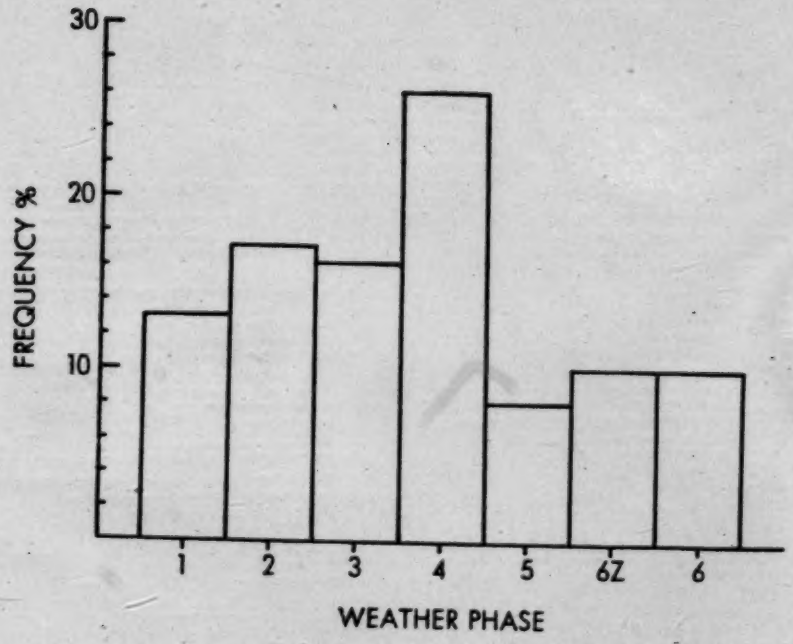


Fig. 5.3: Relative frequencies of each weather phase, April to December, 1979, Toronto.

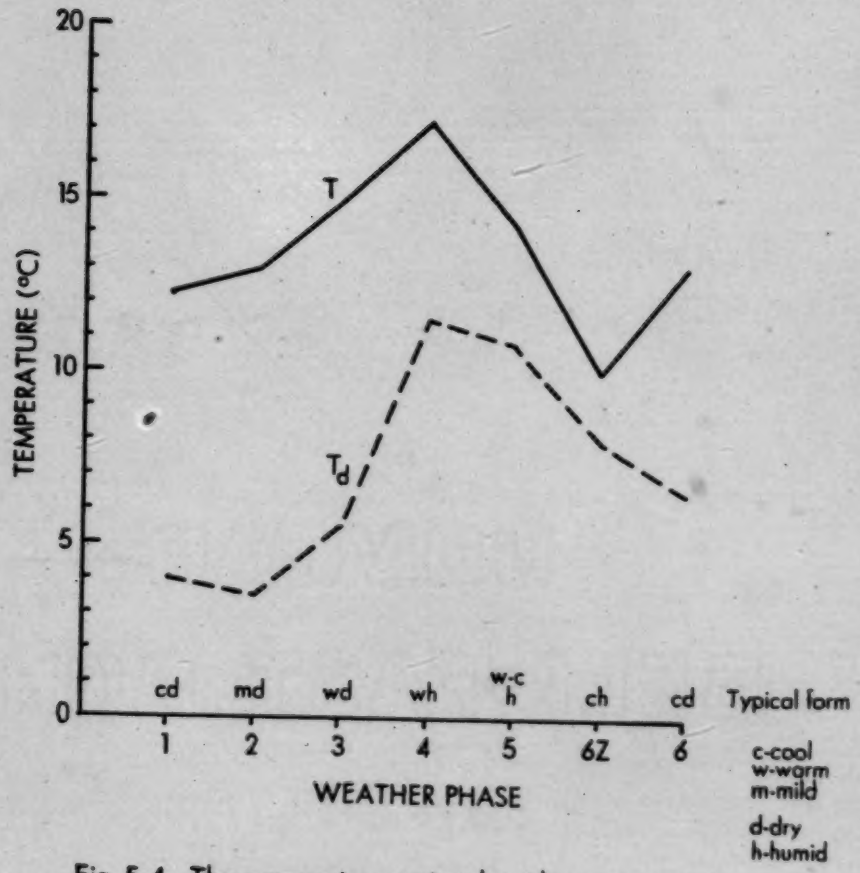


Fig. 5.4: The average temperature-humidity environment for each weather phase at 1300 EST, from April to December, 1979, Toronto.

phases. Phases 1, 2, 3 and 6 are generally dry and are therefore distinguished by relatively low dew points and greater dew point depressions. The humid phases (4, 5 and 6Z) naturally are marked by higher dew points. The air temperature follows the expected pattern, rising consistently from phase 1 to a maximum in phase 4. As the cold front passes during phase 5, the temperature drops rapidly, as does the dew point. It might be noted that these changes in temperature and dew point are similar in amplitude to typical diurnal fluctuations. It is not likely that diurnal fluctuations are as significant a factor in health, however, since they are not accompanied by a change in air mass.

Certain seasonal differences between phases are also evident, most notably the change in mean temperatures. Figures 5.5 and 5.6 illustrate the average meteorological states of the different weather phases during the warmest and coldest months of the study period, July and December, respectively. Aside from the gross changes in temperature, note how the typical forms of certain weather phases are altered subtly. For example, in the summer phase 2 is typically mild and dry. During the winter, however, it becomes cool–cold and dry due to diminished solar heating, even under the clear skies at the center of high pressure.

Naturally, a certain amount of variability in both the temperature and the dew point is going to occur within each phase, but these variations should remain limited so that each phase may be justified as a unique entity. Figure 5.7 illustrates the range of values for each phase that were encountered during the three months of high summer (June, July and August), measured at 1300 EST. The centers of each ellipse mark the mean temperature and dew point for each phase. The ellipses themselves are defined along the abscissa by one standard deviation of the temperature and along the ordinate by the standard deviation of the dew point. This gives an idea of the sort of temperature–humidity zones that each phase encompasses. The only phases which overlap to any extent are 1, 2 and 6 and it is in these three that one would expect overlap, since their differences are largely dependent upon changes in atmospheric stability after the passage of a cold front and on changes in barometric pressure. In fact, some authors simply lump phases 1 and 2 together as one (Kugler, 1978, for example). Phase 3 and 4 exhibit fairly small deviations and both occupy distinct regions on the chart, being well distinguished from the other weather types. Phase 5 and 6Z show a

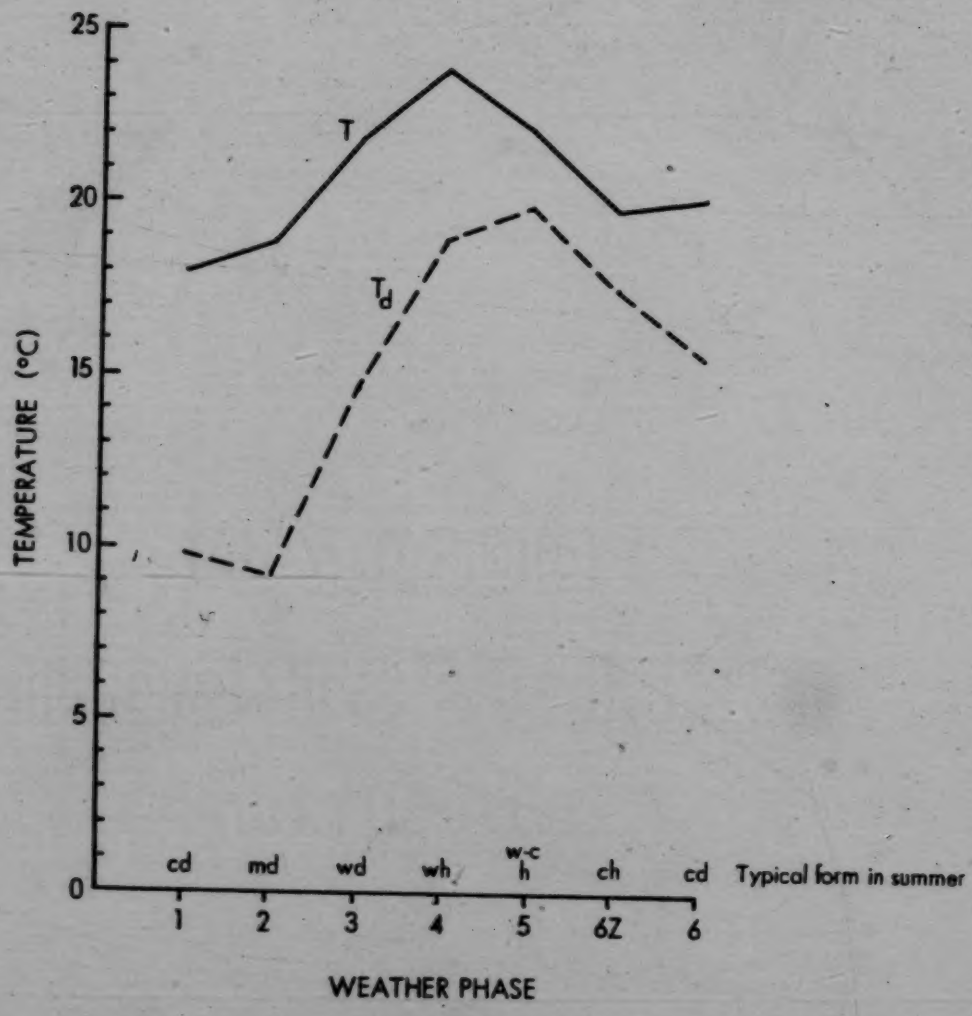


Fig. 5.5: The average temperature-humidity environment for each weather phase during July, 1979

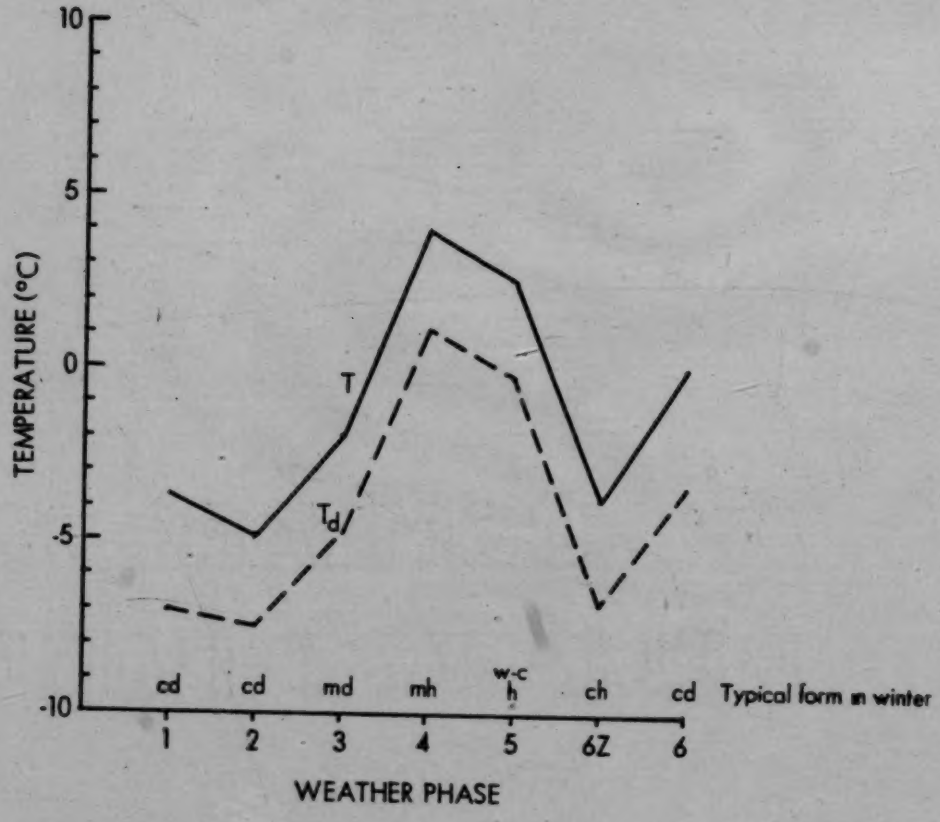


Fig. 5.6: The average temperature-humidity environment for each weather phase during December, 1979

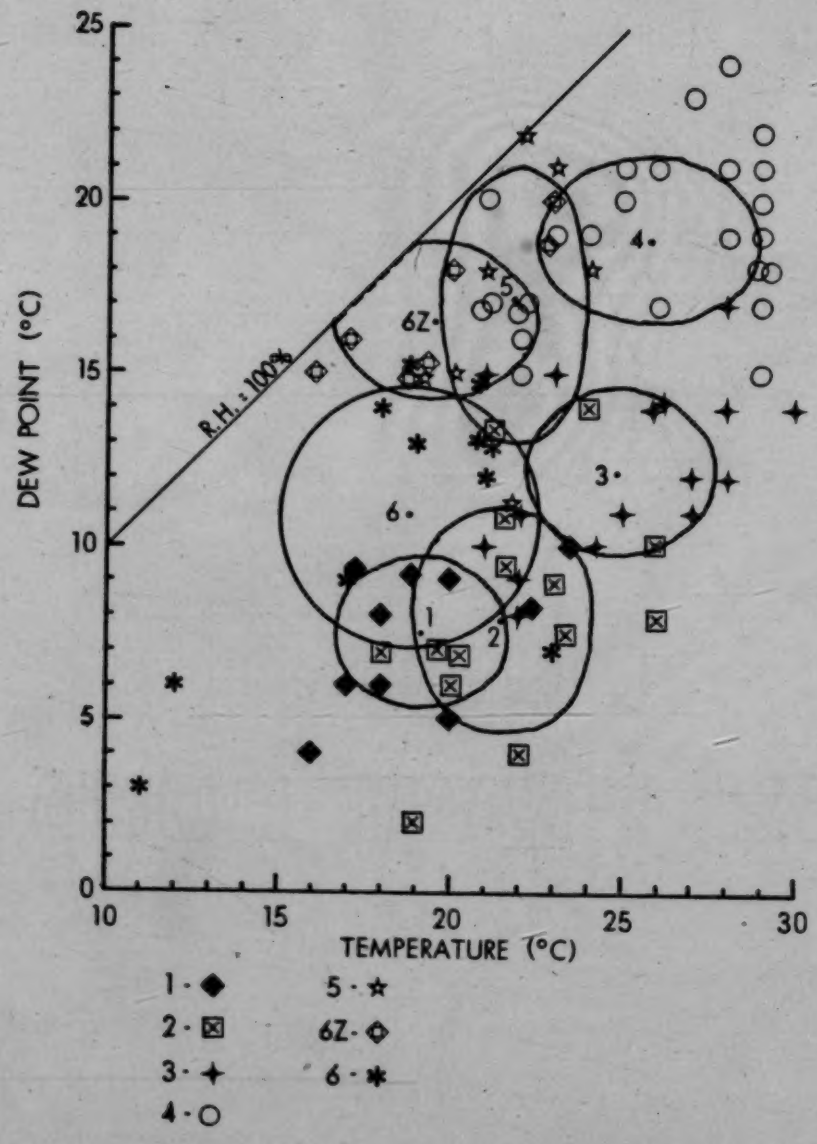


Fig. 5.7: The average temperature-humidity environment for each weather phase during June, July and August, 1979 . Measurements made at 1300 EST. The ellipses are defined by the standard deviations of the temperature and the dew point.

progressive cooling, although the dew point remains relatively high. If one starts at phase 1 and follows the successive centroids, it is easy to see a circular procession of increasing temperature and humidity, peaking at phase 4 with a subsequent decrease back to phase 1 again.

In Figures 5.8a–e, we can observe the actual march of weather phases across the Toronto region as took place from August 31 to September 4, 1879. As the phases change, note the coincident changes in dew point, maximum daily temperature (in brackets), and wind direction. Phase 2 weather prevailed on the morning of August 31 as an invading cell of high pressure from the north dominated most of eastern Canada. Meanwhile, a depression was intensifying in the lee of the Rockies.

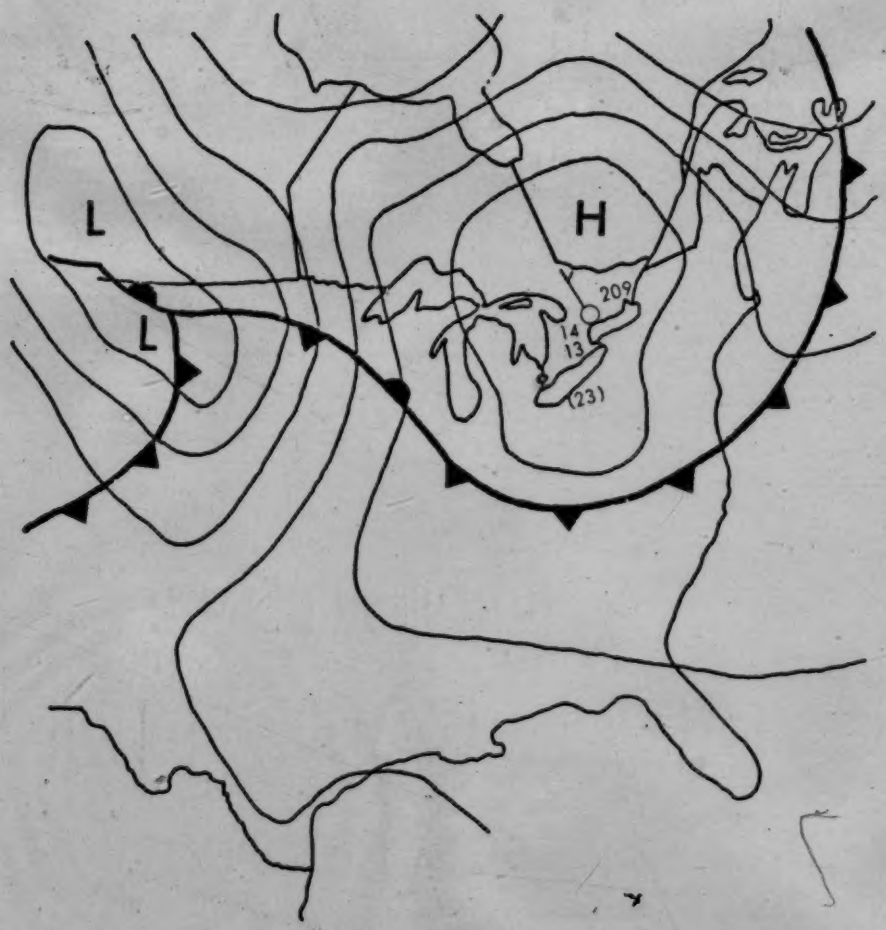
On September 1, the depression had tracked eastward, displacing the high pressure cell and changing the weather to phase 3. The dew point had changed little, but the afternoon maximum reached 27°C.

By the morning of September 2, the warm front had moved to a position extending north–south across central Ontario and the dew point had jumped to 20°C. The heat, humidity and southerly winds were all characteristic of phase 4.

The cold front passage on September 3 was accompanied by a drop in temperature and dew point, although the decrease in temperature was somewhat delayed, not showing a marked decline until 8 or 9 hours after the front had passed. There was also a significant shift in the wind as it reverted to a northwesterly direction.

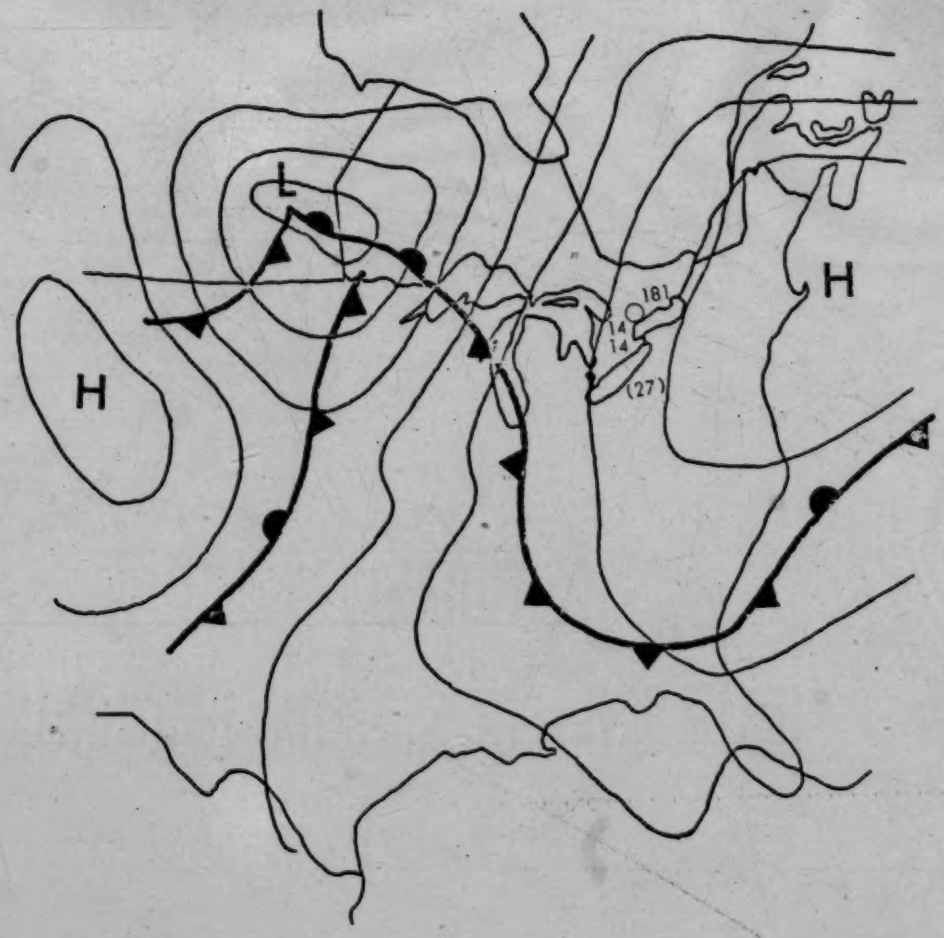
The following day (September 4) was marked by a return to phase 2 conditions after a rapid succession through phases 6Z, 6 and 1. The dew point had dropped substantially and the afternoon maximum was several degrees lower than the previous few days. Notice how another depression is forming to the west, ready to begin the cycle again.

Admittedly, this progression of phases bears a startling resemblance to the textbook model and most cases are not so well–defined. However, keeping in mind that it is the *changes* in temperature and humidity that are important, determining the phases becomes relatively easy, especially in view of the abundant meteorological data available in the hourly reports and the daily maps. The graphs in Figures 5.4, 5.5, 5.6 and 5.7 all indicate that each phase remains quite distinct from the others with the exceptions of 1

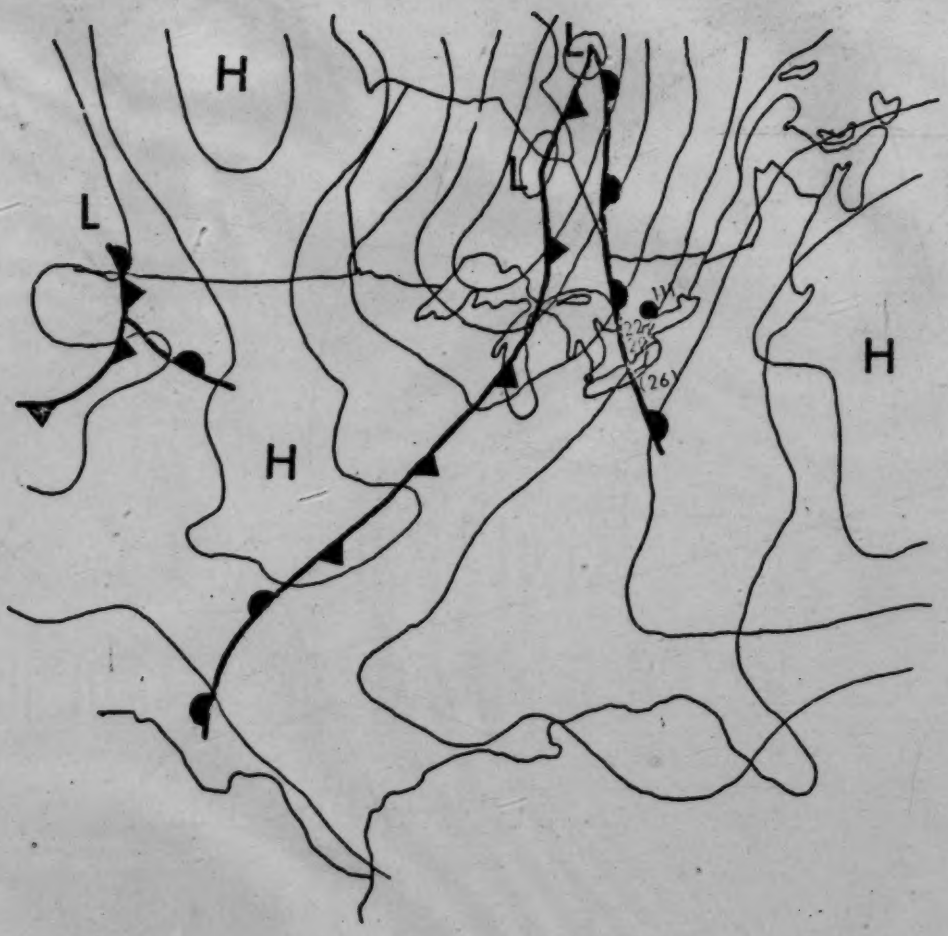


a: PHASE 2 AUGUST 31, 1979 0700 EST

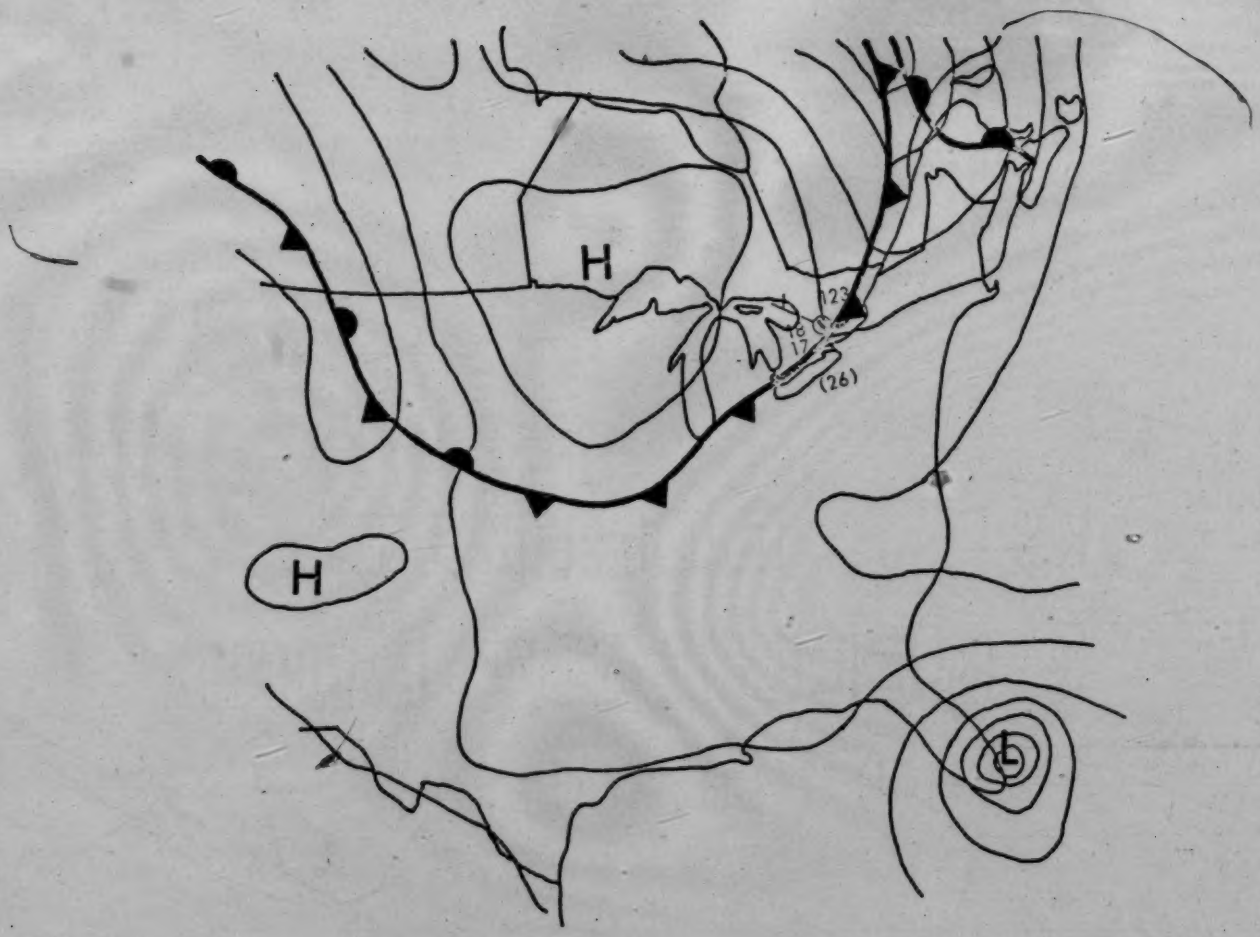
Fig. 5.8a-e: The progression of weather phases at Toronto, August 31 to September 4, 1979. Note the changes in dew point and daily maximum temperature (in brackets). Source: NOAA Daily Weather Maps



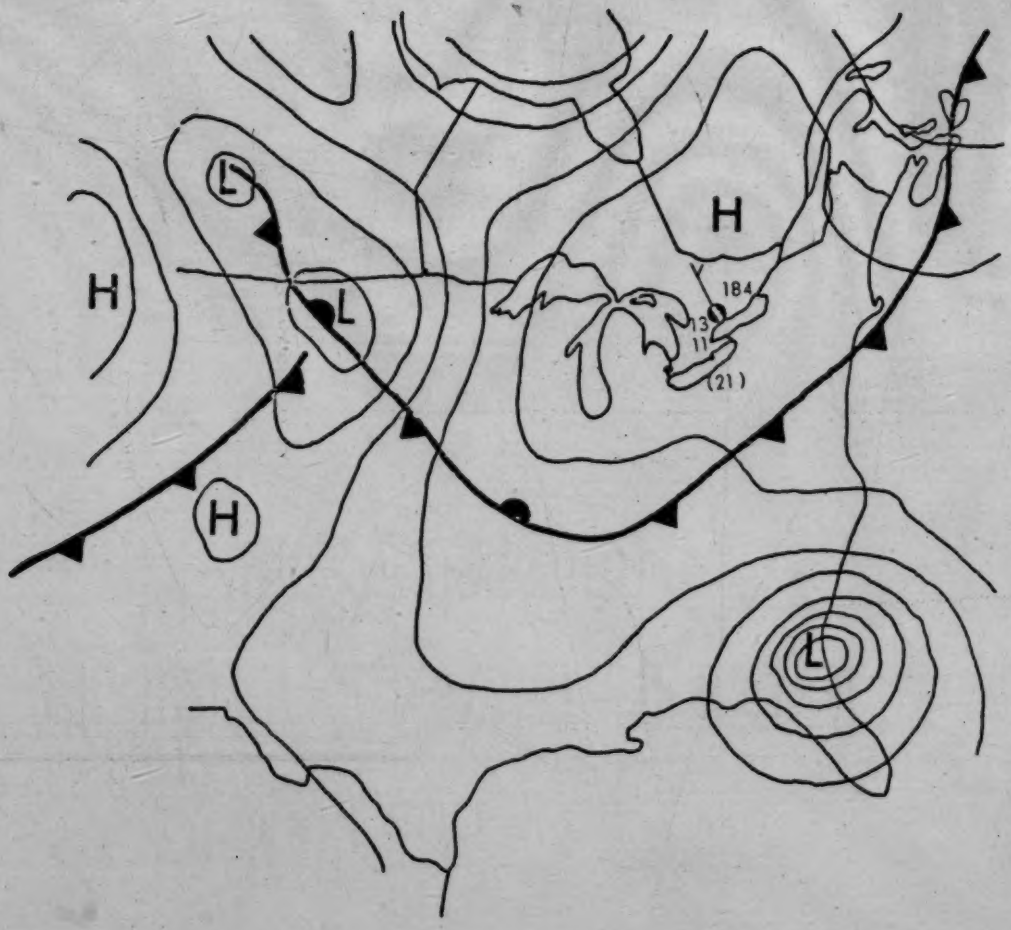
b. PHASE 3 SEPTEMBER 1 1979 0700 EST



c: PHASE 4 SEPTEMBER 2 1979 0700 EST



d: PHASE 5 SEPTEMBER 3 1979 0700 EST



e: PHASE 2 SEPTEMBER 4 1979 0700 EST

and 2 and possibly 6 who do share some common characteristics. These phases can be differentiated, however, by other synoptic features, particularly barometric pressure, wind direction and sky condition.

VI. Methods

A. Background

This project was initiated in November, 1978, as a joint effort between the Migraine Foundation of Toronto and the Canadian Atmospheric Environment Service. A study was conducted over a nine-month period (April-December, 1979), using a total of 91 volunteers from the Greater Toronto area, 70 of whom resided within the boundaries of Metropolitan Toronto. Out of the total sample, 74 (81%) were female and 17 (19%) were male. Of the several hundred volunteers enlisted by the Foundation, 135 responded. Of these, 44 were screened out for various reasons, including inadequate evidence of migraine (common, classic or variations thereof) and residence more than 35 km from the Toronto International Airport, where the weather observations were made. A breakdown of the sample by sex, age and occupation is given in Table 6.1.

B. Data collection

Migraine data were collected from volunteers by means of two forms. Each subject filled out a questionnaire detailing personal statistics (age, occupation, etc.), plus a brief history of their ailment. These questions requested information about migraine problems that they may have encountered in various parts of the world and any relationship that they may have noted between their migraine and flight. This last question was inserted to obtain evidence on the migraine-falling pressure hypothesis.

A detailed record of migraine attacks was kept by each subject on monthly headache logs, listing for each attack the start and finish times, attack characteristics, any additional remarks and the attack severity, based on the relatively objective scale used by Gomersall and Stuart (1973). In this system, severity is divided into 3 categories and each is defined as follows: i) mild, no disruption of daily routine; ii) moderate, some reduction of working efficiency; and iii) severe, total disruption of daily routine. The completed forms were submitted for analysis at the end of each month.

The migraine data were then compared with 11 different weather parameters: atmospheric pressure, the rate of change of pressure, temperature, the rate of change of temperature, wind speed, wind direction, precipitation, thunderstorms, air pollution,

Table 6.1: Demographic breakdown of sample.

	Female (%)	Male (%)	Total (%)
Total	74 (81)	17 (19)	91 (100)
Age:			
<21	5	2	7 (8)
21-30	18	3	21 (23)
31-40	18	3	21 (23)
41-50	15	4	19 (20)
51-60	14	3	17 (19)
>60	4	2	6 (6)
Occupation:			
Housewife	33	0	33 (38)
Indoor: Sedentary	31	13	44 (47)
Indoor: Manual	0	1	1 (1)
Housewife and job	7	0	7 (8)
Retired or Unemployed	2	2	4 (4)
Student	1	1	2 (2)

humidex and Brezowsky's weather phases. In addition, the relationship between day of the week and migraine attacks was also examined.

All weather observations were taken at the Toronto International Airport, with the exception of the air pollution index which was recorded in downtown Toronto. The humidex values were computed from mid-afternoon readings of temperature and humidity using the table calculated by Masterton and Richardson (1979). Precipitation events were taken as the occurrence of any rain, snow or hail, etc. Temperature change was taken as the difference in mean temperature on successive days.

C. Data analysis

The results for each parameter have been graphed on the basis of a percentage deviation from the expected frequency. The expected frequency is determined by the relative frequency of occurrence of each class within a given parameter. For example, if weather phase 1 occurred 15% of the time during the study period, then close to 15% of the migraine attacks would be expected to occur during phase 1, if the outcome were solely the result of chance and no external influences were affecting the results. Therefore, a positive deviation indicates that there occurred a higher frequency of migraine attacks than were expected, signifying a possible aggravating effect. Negative deviations mean that fewer attacks occurred than were expected and thereby indicate possible favourable effects.

Tests of statistical significance were applied to the results to help assess whether or not the deviations observed were significantly different from what should be expected by chance. The test chosen was the nonparametric Kolmogorov-Smirnov one-sample test. The K-S test was preferred over the more familiar chi-square test because it possesses two important advantages: i) there is no restriction on the size of the sample; and ii) the K-S test is generally more powerful than the chi-square (Norcliffe, 1977). Hand in hand with these advantages, however, are several constraints that must be met before the K-S test can be used. Observations must be independent events and measured at the ordinal scale or greater (nominal scale is acceptable for the chi-square) and the population from which the sample is drawn must be continuous.

The technique of statistical analysis was a relatively simple matter of determining if the observed frequency of migraine attacks differed significantly from the expected frequency. In some cases, the chi-square was used as an additional check on the results of the K-S test. In order to determine the significance of particular deviations within one given weather parameter (eg., the significance of the positive deviation exhibited during phase 4 weather), the standardized normal z-test statistic was occasionally used.

It should be noted at the outset that studies of this nature often present the researcher with many difficulties. One problem intrinsic in most biometeorological research is the use of both a physical (weather statistics) and a non-physical (subjective health complaints) data base. Attempts to associate purely objective and numerical

weather data with the subjective complaints of migraine sufferers result in an unfortunate, but unavoidable, disruptive factor. Furthermore, the fact that migraine has been linked to many other potential triggers in addition to weather, such as food, stress, contraceptives and low blood sugar, is another factor that must be considered.

For this reason, the applicability of strict statistical analysis must be questioned somewhat. Although tests of statistical significance are used in this study, it should be noted that placing rigid confidence limits on the non-physical, subjective data is not necessarily realistic, since the subjectivity and noise factors are not accounted for. Although the statistics provide valuable guidelines for analysis, a certain amount of common sense must dictate how interpretations of the data are made. Simply stated, bioclimatic correlations are not often cut and dried.

It is also possible that a certain amount of bias may have existed within the sample used in this study. This bias would have been present for two reasons. Firstly, the subjects were aware that the main objective of the study was to determine the effects of weather on migraine, although they were not aware of what aspects of weather were being examined. Therefore, the sample could be expected to possess a bias towards weather or certain weather conditions as a factor in migraine. This, however, does not appear to be the case, as reflected in the results in Chapter 7. Although falling atmospheric pressure was commonly cited as a migraine precipitant, the results did not show any noteworthy increase in migraine incidence during such times. Furthermore, weather phases, which demonstrated the strongest association with migraine, would not be familiar to the subjects, therefore leaving no preconceptions about the impacts of the various phases to affect the results.

The second possible source of bias was that the sample was not random. This was largely due to the fact that randomizing the sample would have resulted in a much smaller sample size and thus possibly reduced the significance of the results. I felt that the sample size that was used (91 subjects) was near the minimum required for meaningful results.

VII. Results

A. Weather phases:

A marked increase in migraine frequency was associated with weather phase 4 (Figure 7.1) as the observed frequency was 3.4% greater than expected. Conversely, phases 1, 2 and 6 yielded migraine frequencies lower than expected. Phases 3, 5 and 6Z appeared virtually neutral. This distribution was found to differ significantly from the expected at α=0.05, indicating that the results were not solely due to chance and that weather phases appear to affect the frequency of migraine attacks. The frequency of attacks during phase 4 was significantly greater than expected at α=0.05. It is interesting to note the readily identifiable cyclic pattern of migraine incidence which corresponds very well to the sequence of weather phases.

Variations in attack severity also occurred with changes in weather phase (Figure 7.2). Mild attacks were far more frequent during phases 1 and 2 than either moderate or severe attacks. Furthermore, severe attacks demonstrated a distinctly higher frequency during phase 4 and a lower frequency during phase 2.

B. Wind direction:

The largest positive deviation was exhibited by winds from the southeast; easterlies and southerlies had somewhat smaller positive deviations (Figure 7.3). Westerlies yielded the lowest incidence of attacks, but southwest and northwest winds also registered noticeable low values. Northerlies and northeasterlies were only slightly negative. This distribution differed significantly from the expected at α=0.05.

The relationship between wind direction and migraine severity (Figure 7.4) illustrated that severe attacks were more common during periods of wind from the southeast than either mild or moderate attacks. Severe attacks also had a lower frequency during prevailing westerlies than either mild or moderate.

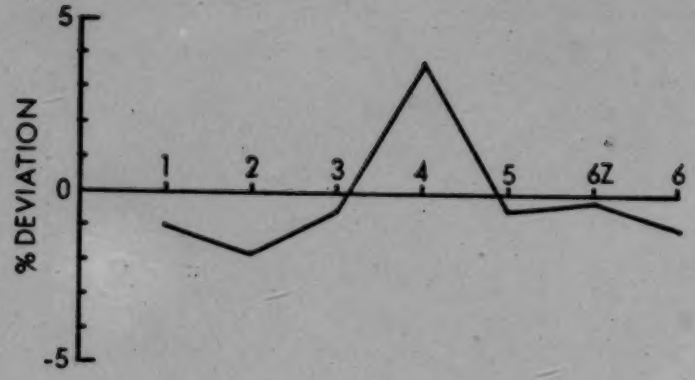


Fig. 7.1: The effect of weather phases on migraine frequency

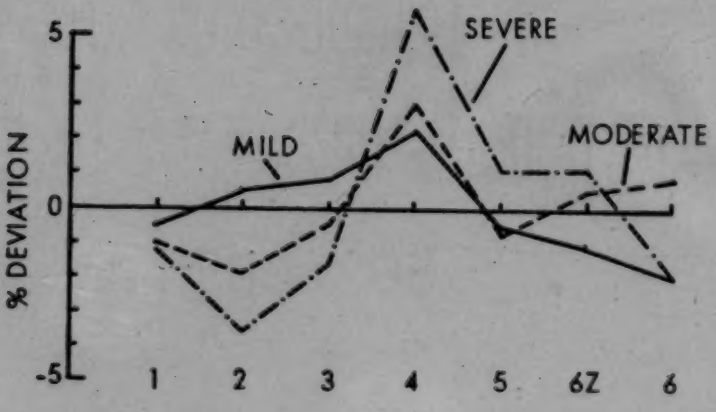


Fig. 7.2: The effect of weather phases on the severity of migraine attacks.

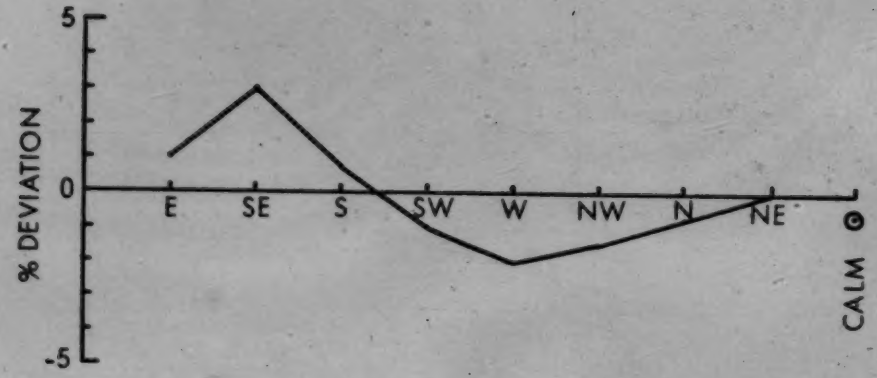


Fig. 7.3. The effect of wind direction on migraine frequency

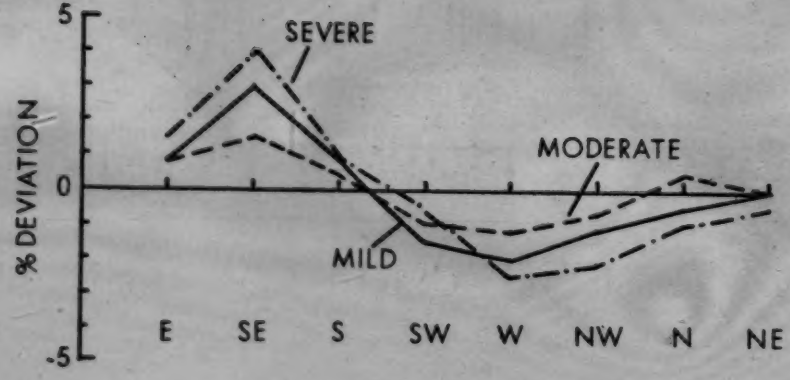


Fig. 7.4: The effect of wind direction on the severity of migraine attacks.

C. Wind speed:

The frequency of attacks versus wind speed exhibited only a very small deviation from the expected (Figure 7.5). The lowest frequency of attacks occurred when the wind was light; the highest was during winds of 21–30 km h^{-1}. Migraine frequency during periods of higher wind speeds showed no marked deviations. This relationship was not statistically significant.

D. Atmospheric pressure:

Two aspects of atmospheric pressure were considered: absolute pressure and the rate of change of pressure.

The absolute pressure trend showed few marked deviations except for a large positive deviation in the range from 101.00 to 101.49 kPa (MSL pressure), indicating an aggravating effect (Figure 7.6). The greatest negative deviation occurred between 102.00 and 102.49 kPa. All other pressures demonstrated only very small deviations, both positive and negative. There was no sign of any noteworthy difference between high and low pressures.

When the rate of pressure change was examined, a very distinct rise in migraine frequency was found to occur during periods of steady pressure (Figure 7.7), that is, those times when the pressure was neither falling nor rising appreciably. All intervals of falling or rising pressure were accompanied by migraine frequencies well below expected.

Figure 7.8 illustrates the relationship between the rate of pressure change and migraine severity. Although the trends for mild and moderate attacks virtually mirror those in Figure 7.7, severe attacks show a distinct difference. Periods of gradually falling pressure were associated with the greatest frequency of severe attacks. There was virtually no deviation during periods of both rapidly falling and rapidly rising pressure, as opposed to the large negative deviations that occurred for both mild and moderate attacks during these pressure tendencies.

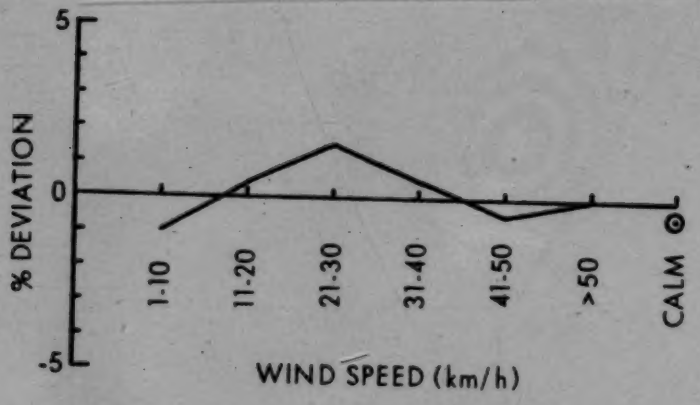


Fig. 7.5: The effect of wind speed on migraine frequency

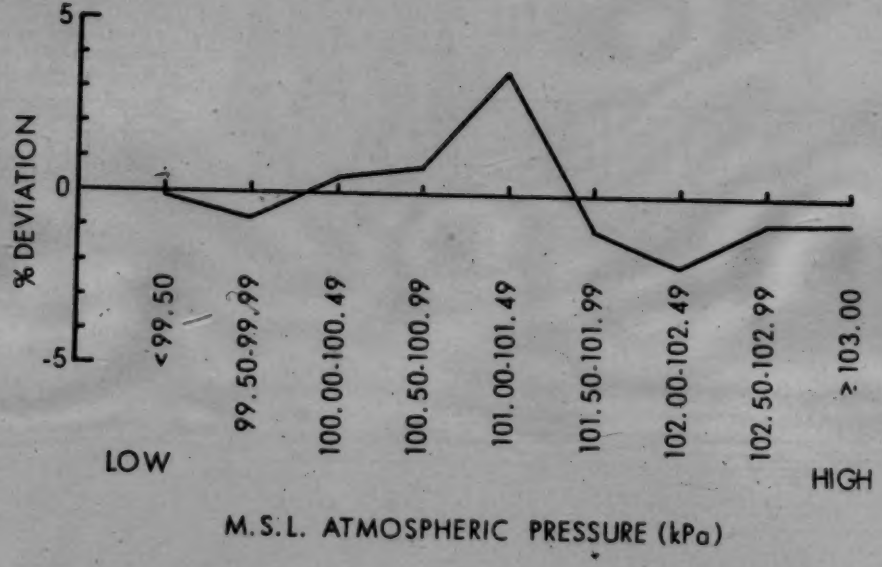


Fig. 7.6: The effect of atmospheric pressure on migraine frequency

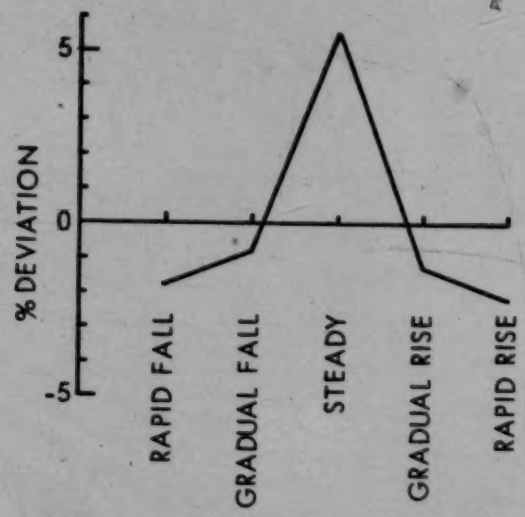


Fig. 7.7: The effect of changing atmospheric pressure on migraine frequency

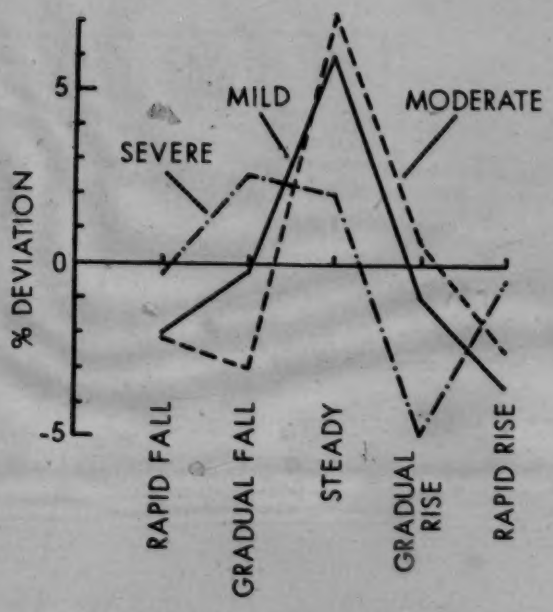


Fig. 7.8: The effect of changing atmospheric pressure on the severity of migraine attacks

E. Temperature:

Again, two aspects of temperature were analyzed: ambient air temperature and its rate of change.

The temperature values revealed a general pattern of increasing migraine frequency with increasing temperature (Figure 7.9). The minimum occurred in the range from 0.1 to 5.0°C. Between 10.1 and 30.0°C, frequencies were higher than expected, with a maximum exhibited for temperatures from 20.1 to 25.0°C. For temperatures above 30.0°C, the deviation was zero.

A readily apparent relationship was found for the rate of temperature change (Figure 7.10). The lowest migraine frequencies occurred during cooling trends, especially when the cooling was large. The opposite was true for warming trends; rapid warming was associated with the highest attack frequency.

F. Humidex:

A distinct rise in migraine frequency accompanied rising humidex values, with a very sharp increase occurring as the humidex rose above 35°C (Figure 7.11). The difference in migraine frequency on days when the humidex was 20°C and on days when it was 30°C was significant at α=0.05. No humidex readings over 40°C were recorded.

G. Precipitation:

During precipitation events, migraine frequency showed virtually no deviation (Figure 7.12).

H. Thunderstorms:

There was very little deviation from expected, although the periods before, during and immediately after a thunderstorm all exhibited slightly higher than expected migraine frequencies, while the migraine frequency decreased when no storms were in the area (Figure 7.13).

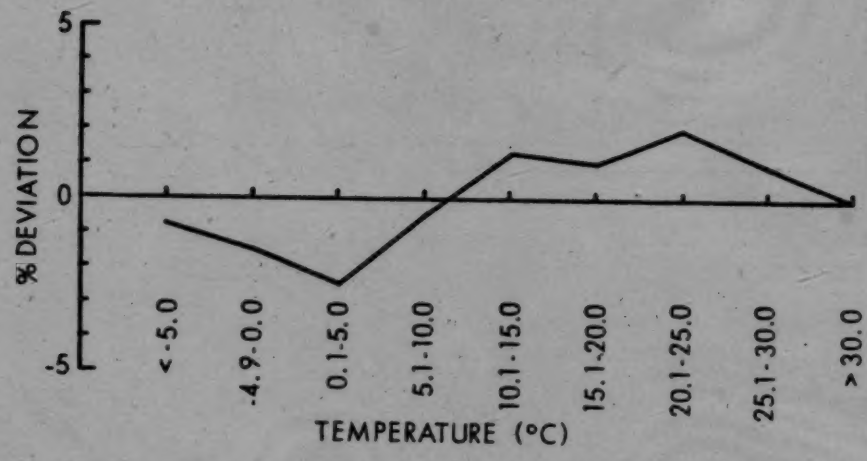


Fig. 7.9: The effect of air temperature on migraine frequency

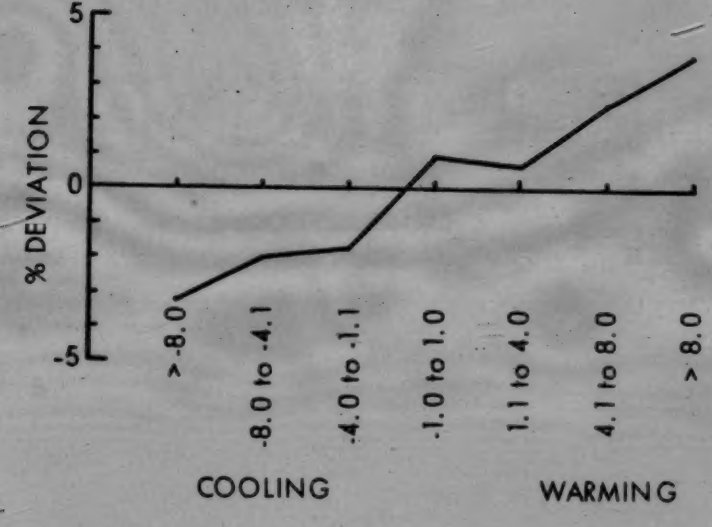


Fig. 7.10: The effect of day-to-day temperature change on migraine frequency

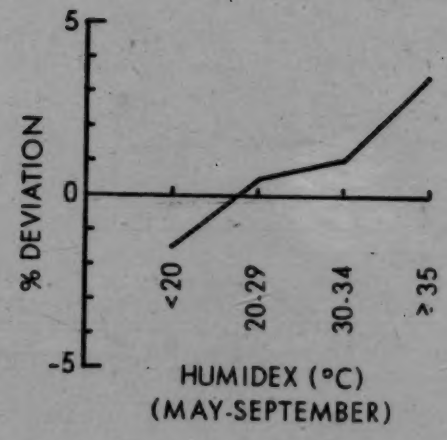


Fig. 7.11: The effect of mid-day humidex values on migraine

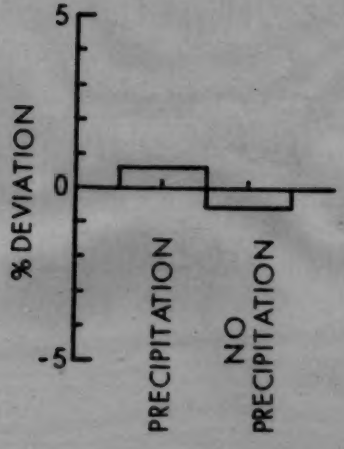


Fig. 7.12: The effect of precipitation events on migraine frequency

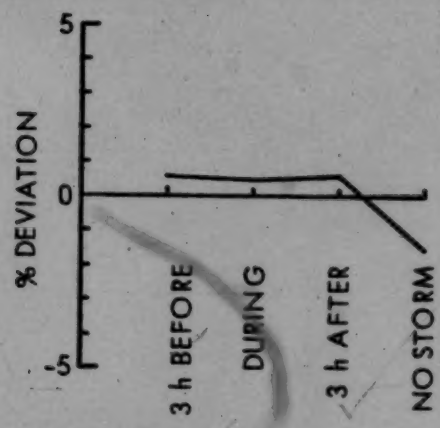


Fig. 7.13: The effect of thunderstorms on migraine frequency

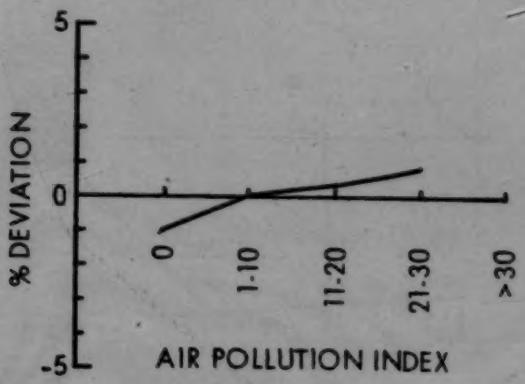


Fig. 7.14: The effect of air pollution on migraine frequency

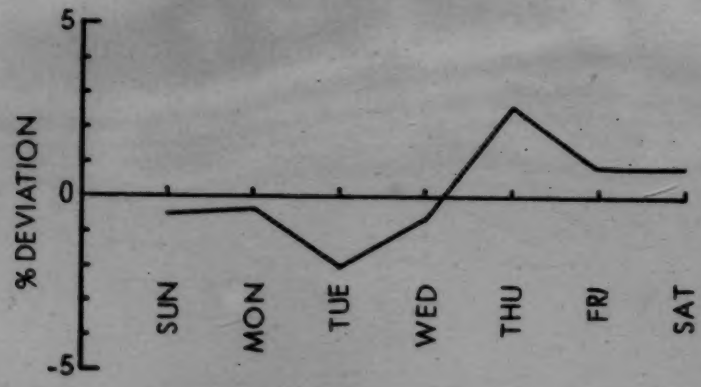


Fig. 7.15: The effect of the day of the week on migraine frequency

I. Air pollution:

Deviations from the expected were very small, although the frequency of attacks rose as the pollution index rose (Figure 7.14). The maximum API value observed was 35, which is not extreme.

J. Day of the week:

The incidence of migraines was the lowest on Tuesday and highest on Thursday (Figure 7.15). Sunday through Wednesday exhibited negative deviations, while positive deviations were observed on Thursday through Saturday.

VIII. The Impact of Weather on Migraine

A. The effects of weather phases

At this point, several factors can be isolated as possessing some control over the frequency and severity of migraine attacks. The most promising of these is weather phases. The results show clearly that specific synoptic weather patterns, as defined by the system of weather phases, exert a stronger physiological effect than most weather parameters taken individually. Significantly, the weather phase–migraine relationship determined here is in general accordance with the findings of Brezowsky (1964), Kugler (1972) and Kugler and Laub (1978). Even more encouraging is that this result is decidedly consistent with most research into the relationship between weather phases and all aspects of human health. As was mentioned in Chapter 5, repeated observations have shown phase 4 to possess a markedly aggravating effect on many clinical ailments, while phases 1, 6 and especially 2 display an ameliorating effect.

There is, however, one important qualification that should be noted: the three migraine studies mentioned previously and, in fact, virtually all weather phase research, have been performed in Europe. Therefore, slight synoptic variations may cause European weather phases to differ somewhat from their North American counterparts. It is evident, though, that the results of this study are very similar to those in Europe, indicating that any differences are likely negligible.

Explanations for this weather phase–migraine relationship are not easily formulated. Kugler and Laub (1978) attribute changes in well-being to disturbances in man's daily internal rhythms caused by weather phases which do not exhibit a similar daily rhythm. They state, "weather phases appear to be examples of powerful synchronizers (for biorhythms). As long as the basic circadian rhythm is undisturbed, man's endogenous biorhythms can adapt themselves readily to such weather phases. However, where there are marked variations in the daily periodicity of weather phases, marked interference with endogenous biorhythms may occur. As a consequence, subjective complaints may develop or symptoms of disease may be triggered" (p. 119). Thus, they attribute the adverse effects of phases 4, 5 and 6Z to their instability, both temporally and spatially. These phases are characterized by rapid changes in pressure, temperature, precipitation,

cloudiness and wind speed and direction. On the other hand, phases 1, 2 and 6 are generally stable, both temporally and meteorologically. It may be that rapidly changing, or unstable, weather conditions are responsible for some of the adverse health effects associated with phases 3 through 6Z, but much more work is needed to assess whether or not a lack of daily periodicity is sufficient to exert such a powerful physiological impact. Furthermore, why does phase 4 stand out as the most aggravating?

The most characteristic feature of phase 4 weather is a rapid rise in both temperature and absolute humidity. Raskin and Appenzeller (1980) suggest that the effects that changes in air temperature have on brain serotonin levels may have some connection with weather-related migraine. They cite work by Myers and Waller (1978) which indicates that brain serotonin levels are elevated during cold stress and that brain serotonin is highly significant in thermoregulation. This certainly provides a tantalizing basis for hypothesizing about migraine and changes in air temperature, although it must be remembered that it is the serotonin in the blood, not in the brain, that has been implicated in migraine. It is beyond the scope of this study to begin suggesting possible serotonergic pathways linking thermoregulation and migraine, but the prospect seems to merit investigation, particularly in view of the the studies done by Tromp and others that reveal poor thermoregulation is widespread in asthmatics and arthritics (see Tromp, 1980).

Work by Brezowsky and Hansen, mentioned in Tromp (1963), clearly demonstrated that blood sugar levels dropped markedly in unfed rabbits during incursions of phase 4 weather. Low blood sugar, particularly when it is brought on by fasting, is a very commonly quoted migraine trigger. Again, it is a long way to extrapolate from rabbits to humans, but the possibility exists that this may also occur in man.

The psychological effects that these weather phases exert on the general population may also be a source of at least a portion of their biotropism, especially since migraine has been shown to be largely dependent on one's emotional state. After all, stress and anxiety are the most common migraine triggers. It is evident from these results and the results of others that weather that is considered unpleasant tends to induce more migraine episodes. Conversely, the clear, dry, agreeable weather associated with phases 1 and 2 demonstrates a marked decrease in migraine frequency and a

general improvement in physical health.

Obviously, the factors that cause phase 4 to exert such a profound influence on health are complex and, aside from the tenuous hypotheses mentioned above, there are no explanations. The main difficulty lies in determining exactly what synoptic components of phase 4 are critical in affecting health. Although heat stress and physical discomfort are usually greatest during phase 4, they only occur during the summer months and fail to account for the irritation caused by phase 4 year-round. It seems likely that the answer lies in one or more factors not largely dependent on season.

In addition to the relationship between migraine frequency and weather phase, there also appears to be an association between weather phase and the severity of attack. The most notable feature of this association is the aggravating effect of phase 4, particularly on severe migraine attacks. During phase 4 conditions, the relative frequency of severe headaches was greater than either mild or moderate ones, thus indicating that phase 4 may tend to irritate and intensify attacks already in progress. Furthermore, the incidence of both moderate and severe attacks dropped during phases 1 and 2, while mild headaches increased in frequency. Gomersall and Stuart (1973) noted that many of their subjects felt weather tended to aggravate their attacks, rather than trigger them. These results indicate that weather phases act to affect both the frequency and severity of migraine attacks and are therefore causative and aggravating.

B. The effects of wind direction

The promising relationship exhibited between wind direction and migraine attacks has several implications. Connections between health and the direction of prevailing winds have been observed as far back as the time of Hippocrates, who noted and catalogued the various ailments that one could expect to encounter while under the influence of any particular wind. The meteorological properties associated with a given wind direction are fairly consistent and are also closely linked to weather phases. Thus, a result relating migraine frequency to wind direction would likely have more meaning to the non-climatologist than one relating it with the rather esoteric weather phases.

The southeasterlies and southerlies that generally accompany phase 4 intrusions of hot, muggy, maritime tropical air into southwestern Ontario are associated with the

highest migraine frequency. Conversely, westerlies and northwesterlies during phases 1 and 2 bring warm, dry, continental air and a resultant decrease in migraine incidence. This relationship between wind direction, weather phase and migraine is important in clarifying the characteristics of the various phases and provides a simple and relatively accurate way to determine which weather phase is prevailing, provided one is aware of the temperature and humidity.

C. The relationship between humidex and migraine

Since the humidex is a measure of physical discomfort, it should be expected to bear some relationship to physical health, especially in the Toronto region where periods of both high temperature and high humidity are common during the summer. The humidity index, or humidex as it is more commonly called, is simply a method for quantifying the discomfort that one feels during periods of both high temperatures and high humidity. It combines the two values to give the temperature equivalent if the air were dry. It is very similar to the wind chill index, except that the wind chill accounts for the cooling effect of the wind and the humidex accounts for the heating effect (or more properly, the reduction in cooling) of humidity. According to Masterton and Richardson (1979), the majority of deaths in Canada related to heat stress occur in southern Ontario, where humidex values are typically the highest in the country. Thus, the fact that migraine incidence increased as the humidex increased is not surprising.

During the summer, phase 4 weather is typified by excessive heat and humidity, which reduce both radiative and convective cooling of the body and greatly diminish cooling due to the evaporation of perspiration. Thus, a great physiological stress is placed on the thermoregulatory system as it attempts to maintain constant body temperature. It is likely that this stress is at least partially responsible for the increased frequency of migraine and may be significant in accounting for the debilitating effects of phase 4. Sacks (1970) also suggests that extreme heat and humidity tend to bring about listlessness and prostration, conditions which can often lead to an attack. Obviously, however, humidex is eliminated as a factor during the winter months (October to April) and therefore fails to explain why phase 4 continues to aggravate health, regardless of season.

D. The effects of atmospheric pressure

The one weather feature most commonly quoted as a trigger by the migraine sufferers in this study is falling atmospheric pressure. Many of the participants cited threshold pressure levels, below which migraines often ensued. Several authors have noted a possible pressure-sensitivity in migraine sufferers. Brainard (1979) mentions "altitude sickness" as a trigger of migraine; Lance (1975) also refers to the effects of altitude and to migraine episodes that have been induced during decompression in a high pressure chamber.

Consequently, the results of this analysis were eagerly anticipated. However, as illustrated by Figures 7.7, 7.8 and 7.9, the results were largely inconclusive and somewhat paradoxical. The fact that most attacks occurred when the pressure was between 101.00 and 101.50 kPa (MSL) does not likely indicate any significant pressure relationship, since this is in the range of standard atmospheric pressure. The extremes of pressure, both high and low, yielded lower than expected migraine frequencies. In light of the information supplied by migraineurs claiming pressure-sensitivity, the expected result would have exhibited the highest frequencies during extremely low pressure and the lowest during high pressure.

Similar results occurred in the analysis of changing pressure. The association between high migraine frequency and periods of falling pressure failed to materialize. Instead, the highest frequency occurred when the pressure was stable, quite the opposite of anything that has been suggested by migraine sufferers. Again, the absence of adverse effects from either extreme of pressure change is paradoxical. Both falling and rising pressure correspond to fewer attacks than expected.

Why such a persistent complaint should register such inconclusive results is difficult to say. No investigation into the migraine-pressure relationship has been able to correlate the two satisfactorily, with the exception of Gomersall and Stuart (1973) whose findings were opposite to generally held beliefs. Lance (1975) proposed that pressure-aggravated migraine may be the result of hypersensitivity by migraineurs to the pressure of oxygen in the blood. This, however, is unsubstantiated. The relationship between migraine and atmospheric pressure is discussed further in Chapter 9.

E. The effects of temperature

Temperature effects were largely inconclusive, due in part, perhaps, to the absence of any extremes of hot or cold. Interestingly, the highest attack frequency corresponded to the range around room temperature, usually considered to be the most comfortable temperature for human activity. The lowest attack frequency occurred during lower temperatures, contradictory to many comments from migraine sufferers who felt that chilling of the body often led to an attack. Perhaps extremely low temperatures would have proved unfavorable. However, it must also be remembered that the effects of outside air temperature are easily eliminated by going indoors.

Temperature change demonstrated a trend worth noting. Rapid rises in temperature, which are associated with passing warm fronts and therefore the onset of phase 4, recorded the most unfavorable influence on attack frequency. It is difficult to tell whether it was the temperature change itself that was affecting the migraine incidence or whether the connection with warming trends was just a reflection of the effects of phase 4 as a whole.

F. Other meteorological parameters

Thunderstorms are a commonly cited migraine precipitant. Most often, attacks are reported to be most severe just prior to the onset of an electrical storm; with its arrival, the symptoms appear to be alleviated somewhat. One hypothesis that comes to mind supporting this relationship, although there seems to be no direct evidence to confirm it, is the effect that thunderstorms have on the electrical charge distribution in the atmosphere. Studies of the charge distribution within electrical storms indicate that the subcloud air becomes more positively ionized at the edges of the thundercloud, while the actual storm rainfall creates an area of increased negative ionization (Moore and Vonnegut, 1977). If one considers that increases in positive ionization tend to be biologically aggravating, while negative ions appear to possess beneficial effects (Krueger, 1972; Sulman 1976), it is possible that changes in atmospheric ionization brought on by thunderstorms may influence health.

The thunderstorm–migraine correlation achieved here is tenuous at best. It demonstrated little deviation from expected. However, attacks did increase in frequency

during thunderstorms and decreased when no storms were present, thus lending some support to a possible link between the two.

The slightly greater number of migraines observed than expected during precipitation events does not indicate a very striking relationship. However, one could expect a strong psychological effect on rainy days as people are often forced to stay indoors, change plans and generally limit their activities. It is perfectly conceivable that the psychological letdown on these days may stimulate a slight upswing in migraine frequency.

The fact that wind speed yielded virtually no trend whatsoever is not really surprising. Even though chill winds blowing on the face are often quoted as a migraine trigger, it should be remembered that wind speed is highly localized at the ground and is easily escaped. Thus, any biotropic effect it may possess is readily obscured.

G. Daily and seasonal effects

Previous research has indicated that weekends, and particularly Saturday, are associated with increased migraine frequency (Gomersall and Stuart, 1973; Lance, 1978). There are two possible mechanisms to account for this. Relaxation on the weekend after a stressful work week may tend to dilate blood vessels and therefore increase susceptibility to an attack. Also, extended hours of sleep on Saturday and Sunday mornings causes a build-up of carbon dioxide in the blood, possibly stimulating the onset of migraine since carbon dioxide is a potent vasodilator.

The results of this study showed a slightly higher than expected frequency on Saturdays, but lower than expected on Sundays. Furthermore, the maximum was on Thursday. There appears to be no good reason for this.

Figure 8.1 illustrates the seasonal trend in migraine frequency from April to December, 1979. Although no sound conclusions about seasonal effects can be drawn from only nine months of data, several comments can be made. There is an obvious spring maximum and a double minimum, in August and November. The monthly decrease in migraine frequency from April to August is remarkably consistent, although why it tends to vary so markedly after August is hard to say. The most significant point may be the relationship between the April maximum and the period of extremely unstable

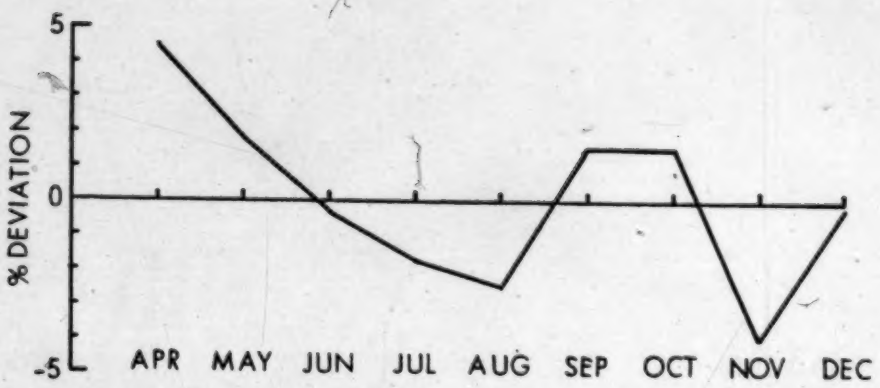


Fig. 8.1: Monthly variations in migraine frequency (period April to December, 1979)

atmospheric condtions that occurred during that month, when the unusually rapid passage of four major depressions within ten days, accompanied by very stormy weather, was associated with a substantial increase in migraine incidence.

IX. A Brief Investigation into the Effects of Atmospheric Pressure Under Semi-Controlled Conditions

It should be emphasized that the results obtained during the nine-month weather-migraine study were observed under normal living conditions for the participants. Many of them were on prophylactic or symptomatic medication and naturally took precautions against any factors that they recognized as having a role in their migraine attacks. Although weather is generally an all-pervasive environmental factor and difficult to avoid, several precautions against some of its effects can be taken, such as dark glasses to shield from glare and using air-conditioning on hot days. Thus, the results of this study give an indication of the extent to which weather figures as a migraine trigger in a person's normal environment.

More exacting analyses of atmospheric effects, and the effects of any other trigger, can be carried out under laboratory conditions. The use of climatically-controlled chambers allows each climatic variable to be precisely governed and many noise factors to be eliminated. Exposure of migrainous subjects to any given weather parameter under controlled conditions is the ultimate method for observing and exploring the connection between weather and migraine. The unfortunate fact remains, however, that the facilities required for this type of experimentation are not commonplace.

In an attempt to further clarify the elusive pressure-migraine relationship, volunteers in this study were asked to describe any experiences that they might have had during flight, since the cabin of a modern airliner provides an excellent example of a decompression chamber. The pressure changes that an aircraft undergoes during ascent and descent, even when pressurized, are far greater than anything experienced under natural atmospheric conditions at the surface. Therefore, any pressure sensitivities should be effectively exposed.

The average rate of climb of a modern jet aircraft is 1000-1300 m per minute. As the aircraft climbs, its cabin pressure decreases, although at a much slower rate. The rate of decompression is generally around 1.0 kPa per minute and lasts about 10-15 minutes until the desired cabin pressure is reached, usually about 85 kPa. Thus, a pressure drop of approximately 15 kPa in 15 minutes occurs during ascent, a rate far

greater than any atmospheric conditions at the surface could ever produce. While this rate of change is extreme, it provides no more discomfort to the average person than the familiar "earpopping". The rate is similar during descent although the pressure is increasing rather than decreasing.

Five of the 91 participants in this study had never flown. For the remainder, 13 reported chronic migraine attacks during flight, 14 had irregular episodes, 42 had never experienced an attack and 17 were uncertain (Table 9.1).

The most significant result is that 48% of the respondents had never experienced an attack during flight, while only 16% complained of a recurrent problem. Interestingly, all but one in the latter group were female. Also, a disproportionately large number of the males reported no migraine-flight connection.

Of those who reported a persistent migraine problem while flying, most mentioned takeoff and landing as the critical periods. Often these attacks lingered for days, perhaps a function of jet lag. One of the most severe attacks reported occurred on an unpressurized DC-3, where the effects of decreased pressure with altitude would be maximized.

There are many other factors, however, that could logically precipitate migraine attacks during flight. Stress and anxiety are often prevalent during long trips. Jet lag certainly weakens the body's defences against an attack. Therefore, several noise factors must still be taken into account.

The results of this little sidelight to the study, and admittedly the results are highly subjective, appear to indicate that a large proportion of the migrainous community have no noticeable pressure-sensitivity. However, a small, yet significant proportion, largely female, are apparently susceptible to pressure changes. At what rate this pressure change needs to take place is unknown. It does seem likely, though, that atmospheric pressure changes at the surface need not concern most migraine sufferers, except perhaps to indicate approaching adverse weather conditions such as phase 4.

Table 9.1: Susceptibility to migraine during flight.

	Female	Male	Total (%)
Total	70	16	86 (100)
Recurrent Problem	12	1	13 (16)
Never	31	11	42 (48)
Irregular	11	3	14 (16)
Uncertain	16	1	17 (20)

X. Conclusions

A. Summary of the results

Migraine is a hyperreaction to internal and external stimuli (Dalessio, 1980). The assorted symptoms associated with migraine, most notably headache, are a consequence of this hyperreactivity. The results of this study show that certain weather conditions provide a stimulus of sufficient magnitude to provoke the onset of migraine attacks. The most significant findings of this investigation into the relationship between weather and migraine in southwestern Ontario are:

1) In general, certain synoptic weather patterns as defined by Ungeheuer and Brezowsky's scheme of weather phases exerted the most physiological control of all the weather features examined. The most aggravating weather type was the passage of a warm front and the warm tropical air that followed behind the front (weather phase 4). High pressure cells of clear, sunny and dry weather (phases 1, 6 and especially 2) had ameliorating effects on migraine. The reasons for phase 4's adverse impact are difficult to determine. It is likely the result of two or more factors acting together.

2) The results of the weather phase analysis were in agreement with previously published findings, not only on weather and migraine, but on weather and health in general. The passage of fronts, both warm and cold, consistently tend to aggravate many clinical symptoms. This is probably a function of the sudden change in atmospheric conditions that usually occurs during the transition from one air mass to another.

3) During the summer months, the humidex discomfort index correlated very well with migraine frequency. As the humidex value and its accordant physiological heat stress rose, so did the incidence of migraine.

4) Wind direction correlated well with both weather phases and migraine frequency, thus providing a relatively simple means for identifying weather phases and their associated physiological effects. Southerly winds are generally an omen of biologically-adverse weather.

5) Atmospheric pressure did not appear to exert a profound influence on migraine, although a small number of sufferers did exhibit pressure-sensitivity under extreme rates of pressure change.

6) Gomersall and Stuart (1973) mentioned that some migraine sufferers believed weather tended not so much to trigger attacks, but rather increased the severity of attacks in progress. The results of this study show that there was a marked increase in severe attacks during unfavourable weather conditions, whereas mild attacks were not nearly as frequent. This seems to support the prospect that weather may aggravate attacks in some people rather than trigger them.

7) Synoptic weather patterns appear to have more control over physical well-being than individual weather elements, such as temperature and pressure. Why this is so is not evident at present, but effects on health have been consistently correlated with weather phases, while correlations with single weather parameters are often not successful.

8) The etiology of migraine is not well understood and this greatly complicates explanations as to why weather influences migraine attacks. One consistent feature of the results presented here is the increased frequency of migraine during weather periods that are generally considered unpleasant. Since migraine often results from emotional stress or anxiety, it may be possible that mild psychological letdowns associated with disagreeable weather are sufficient to trigger the patho-physiological changes necessary to stimulate a mild attack.

B. Implications for further research

1) Because the exact cause of migraine is not completely understood, applied migraine research is greatly complicated. Recent studies have come relatively close to formulating a general theory for the migraine mechanism, ie., the "cerebral vasospasm" resulting from a hypersensitivity to various stimuli (Lance, 1978; Dalessio, 1980; Raskin and Appenzeller, 1980). The major problems that remain to be resolved, however, are the roles that serotonin, prostaglandins and the various other hormonal agents play in migraine. Serotonin is of particular importance, not just because of its central role in migraine, but also because of its tremendous significance in such a wide variety of physiological mechanisms, including thermoregulation. It is likely that the pathways involved in weather's impact on migraine are connected with at least one of these agents (probably serotonin), but this remains purely speculative.

2) The adverse effects on health of weather phase 4 is a perplexing problem. The consistently aggravating effects of this weather phase indicate a strong biological effect. However, the complex variety of atmospheric conditions that occur during this phase precludes any easy explanations. The fact that phase 5 is also unfavourable leads one to believe that the exchange of air mass is significant.

3) Research has been performed all over the world on the patho-physiological effects of local winds, especially the Sharav and the Foehn. There is, however, virtually no literature on the effects of the Canadian Chinook. This wind is widely believed to have effects on both physical and mental health. Some believe the Chinook has favourable effects; others feel it is irritating. Unfortunately, no scientifically controlled observations have been made. Studies are presently underway at the University of Lethbridge into the behavioral impacts of the Chinook, but much more research into its biological properties is merited.

4) The difficulty of performing biometeorological research cannot be overestimated. The formulation of relationships between weather and health is inherently complicated by the use of generally subjective complaints and by the tremendous physiological variability exhibited by humans. However, there can be no doubt that certain weather-health connections do exist and they warrant extensive research. Understanding the interactions between the atmosphere and man's physiological, pathological and biological activities will enhance the well-being of both mind and body.

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